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13. ABSTRACT

This report documents the Dynamic Planning model developed as part of the third phase of the Integrated Facilities Requirements Study (IFRS).

In Phase I, two analytic submodels were developed. The first, a Logistics Support Requirements Generator, estimates personnel, aircraft, and fuel requirements for each phase of undergraduate pilot training at the Naval Air Training Command (NATRACOM). The second, a Pacing Facilities Requirements submodel, calculates facility requirements for each phase of training.

The purpose of the Phase II study was to develop a preliminary total systems IFRS management planning tool (including the two submodels developed in Phase I, as well as Base Loading, Facilities Excess/Deficiency, and Total Cost submodels), and automate the model so that it provides quick, accurate, and relevant information for use in the decision-making process. This Static IFRS model has been in continuous operation since March 1970.

The purpose of the Phase III study was to refine the Static IFRS model and to expand the IFRS concept by developing three additional planning tools for use by Navy decision-makers as follows:

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- Dynamic planning tool
- Optimization model
- Fleet Readiness Training Squadron planning tool.

The Dynamic planning tool simulates the undergraduate pilot training program on a weekly basis whereas the Static IFRS assumes an even annual flow of students. The Optimization model has two segments - a PTR Maximizer that calculates the maximum annual pilot training rate (PTR) possible for a given facilities inventory and a MCON Minimizer that calculates the minimum facility cost phase-to-base assignment for a desired PTR. The Fleet Readiness Training (FRT) model provides planning information for the readiness training squadrons and is designed similarly to the Static IFRS model. The Phase III documentation consists of the following four reports:

- The Integrated Facilities Requirements Study (IFRS) Phase III, ORI TR 645

- Development of the Automated Dynamic Model for the Integrated Facilities Requirements Study (IFRS) Phase III, ORI TR 646

- Development of the Optimization Model for the Integrated Facilities Requirements Study (IFRS) Phase III, ORI TR 647

- Development of the Fleet Air Readiness Training Model for the Integrated Facilities Requirements Study (IFRS) Phase III, ORI TR 648.

This report documents the Optimization model. Volume I contains a Summary of the two submodels - The PTR Maximizer and The MCON Minimizer. Volume II contains the Detailed Model Formulation, User Instructions and an appendix of the functional relationships.

OPERATIONS RESEARCH, Inc.

SILVER SPRING, MARYLAND

Development of the Optimization Model for the Integrated Facilities Requirements Study (IFRS) Phase III

Volume II – Formulation and Use of the IFRS Optimization Model

31 March 1971

Prepared under Contract N00025-67-C-0031 (NBy-78672)
for the Naval Facilities Engineering Command
Department of the Navy
Washington, D.C.

FOREWORD

This report documents the Optimization model developed as part of the Integrated Facilities Requirements Study (IFRS). It has been prepared for the Systems Analysis Division of the Office of the Assistant Commander for Facilities Planning (Code 20), Naval Facilities Engineering Command (NAVFAC), Department of the Navy, as part of Contract N00025-67-C-0031 (NBy-78672) awarded to Operations Research, Inc., in June 1970.

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- Dynamic planning tool
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The Dynamic planning tool simulates the undergraduate pilot training program on a weekly basis whereas the Static IFRS assumes an even annual flow of students. The Optimization model has two segments—a PTR Maximizer that calculates the maximum annual pilot training rate (PTR) possible for a given facilities inventory and a MCON Minimizer that calculates the minimum facility cost phase-to-base assignment for a desired PTR. The Fleet Readiness Training (FRT) model provides planning information for the readiness training squadrons and is designed similarly to the Static IFRS model. The Phase III documentation consists of the following four reports:

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This report documents the Optimization model. Volume I contains a summary of the two submodels—the PTR Maximizer and the MCON Minimizer. Volume II contains the detailed model formulation, user instructions and an appendix of the functional relationships.

These IFRS models were developed and programmed by the staff members of the Economic Analysis Division of Operations Research, Inc., under the direction of Dr. William J. Leininger, vice president and division director, and Thomas N. Kyle, program director. The project team members included R. J. Craig, M. C. Fisk, W. Liggett, F. McCoy, R. Messalle, and R. Yockman.

Mr. Dennis Whang of the Systems Analysis Division of Facilities Planning was contract monitor for NAVFAC. In addition, valuable assistance was provided by many other Navy personnel including, in particular, those in the Office of the Staff Civil Engineer and the Training/Plans Division of the Naval Air Training Command, the Aviation Training Division of the Chief of Naval Operations, and in the Systems Analysis Division of NAVFAC. The authors gratefully acknowledge the contributions made by all of these people to the development of the IFRS models.

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I. INTRODUCTION

1.1 This volume provides an in-depth discussion of the development of the component parts of the IFRS Optimization model. A summary discussion of the model is contained in Volume I of this report. Since the Static IFRS model is the basis for this Optimization model, the reader should fully understand the Static IFRS prior to reading this volume.

1.2 The Optimization model consists of two separate submodels—the PTR Maximizer and the MCON Minimizer. Both employ linear programming as the optimization algorithm, and both have been programmed and are operational on batch processing computers.

1.3 Section II contains brief introductory discussions on linear programming, how the Static IFRS model was adapted to the LP format, and the other optimization techniques considered. Section III contains a detailed discussion of the MCON Minimizer submodel, while Section IV contains a detailed discussion of the PTR Maximizer submodel. Finally, the functional relationships required to calculate the coefficients and the tables of coefficients are included in the Appendix.

II. GENERAL

OPTIMIZATION TECHNIQUES CONSIDERED

2.1 The following candidate optimization techniques were considered for this developmental model:

- Simulation and search
- Dynamic programming
- Nonlinear programming
- Mixed integer programming
- Linear programming.

The technique ultimately selected was linear programming. Pertinent comments on the other candidate techniques and a short description of each follow.

Simulation and Search

2.2 Simulation and search involve running the total Static IFRS model for all reasonable combinations of phase-to-base assignment and the enumeration of the outcomes. The least cost scenario is then selected by searching the total system cost for each run. A major problem with this technique is the large amount of computer time needed to perform such an analysis, since the number of combinations of phase-to-base assignment is very large. This technique works quickly only if the optimal assignment is very much like the present assignment.

Dynamic Programming

2.3 Dynamic programming is a technique which is useful in optimizing processes in which there are a number of discrete states. The pilot training program does have a number of discrete stages (i.e., there are a number of pipelines, each containing several phases of training). However, dynamic programming is efficient only when there is a small number of states (conditions). In this case, each combination of PTR and phase-to-base assignment is a state. The very large number of states obviates the use of dynamic programming.

Nonlinear Programming

2.4 Nonlinear programming provides a means of optimizing nonlinear functions subject to nonlinear constraints. While the pilot training program fits such a description, there is a shortage of available solution algorithms. There are only a few nonlinear programming algorithms and the ones which do exist have many problems. Chief among these problems is efficiency—with a problem of this size the algorithms may take hundreds of hours of computer time, and due to roundoff errors and other scale problems there is no guarantee that optimality will be reached.

Mixed Integer Programming

2.5 Mixed integer programming allows the optimization of problems in which certain of the variables take on only integer values, e.g., aircraft runways. The problems with mixed integer programming are the same as with nonlinear programming, particularly the lack of efficient algorithms. Another problem with mixed integer programming is the size of the computer necessary to handle such problems. Few computers have enough internal storage to handle a problem the size of the pilot training optimization. The use of integer programming was investigated extensively, but the size of the Optimization model precluded its use.

Linear Programming

2.6 Linear programming (LP) was selected as the optimization algorithm for the IFRS system. It was determined that the efficiency of LP as an optimization algorithm outweighed the costs in terms of lack of precision entailed by assuming linearity and continuity (no integer variables). The detailed assumptions necessary to fit the IFRS system into an LP format are described subsequently.

LINEAR PROGRAMMING AS THE OPTIMIZATION TECHNIQUE

Selection of Linear Programming

2.7 Linear programming (LP) is a mathematical technique for calculating the optimum allocation of resources necessary to achieve a particular objective.

Generally, the linear programming formulations have two forms (subject to certain resource constraints)—maximizing output for a given resource level or minimizing cost for a given output level. The use of LP requires that all functional relationships must be continuous linear functions. Many of the equations of the Static IFRS model are continuous linear functions and all can be approximated as such. The accuracy lost by assuming linearity and continuity is believed to be more than offset by the efficiencies gained by using LP. The size of this pilot training problem is large and thus it was imperative to select a technique that would operate economically within a reasonable time period. Many LP packages are available and there are many published documents which describe them. The length of time available to this study dictated that maximum use of current optimization packages had to be made if the study were to be timely and to have utility.

LP Format

2.8 The mathematical equation describing the objective is called the objective function; the resource limitations (in equation form) are called constraints and the maximum or minimum value of the constraints is called the right-hand side (RHS). The basic format of the linear programming problem is shown in Figure 2.1. The full formulation of the problem requires that the possibility of not using all of the available resources (i.e., b's) must be accounted for. This involves the addition of so-called slack activities to the A matrix. These slack activities reflect the nonuse of available resources. This addition allows the inequality signs to be removed so that the problem can be expressed as a system of simultaneous equations with more unknowns than there are equations. The LP algorithm then solves this system for the maximum or minimum value of the first equation (i.e., the objective function). While it is possible that no solution to this system exists (i.e., the problem is infeasible); if one does exist, then the algorithm can be used to solve for an optimum.

Solution Algorithm

2.9 The solution algorithm for linear programming problems consists of a number of steps, some of which are repeated iteratively. The first step is the selection of an initial feasible solution which becomes the first current solution. The second step involves choosing an activity from those activities not in the current solution which will improve the objective function. The third step is to choose that activity in the current solution which is to leave the current solution. This introduction and removal of activities cause an improvement in the objective function. Then steps two and three are repeated (i.e., each repetition is called an "iteration") until no further improvement in the objective function is possible. At this point, the solution is optimal.

2.10 While the preceding discussion is quite brief, a conception of what LP is and what it does will aid in understanding the construction of the optimization submodels.

MAX/MIN $\quad Z = c_1x_1 + \ldots + c_mx_m \qquad (2.1)$

subject to

$$a_{11}x_1 + \ldots + a_{1m}x_m \lesseqgtr b_1 \qquad (2.2)$$

$$\vdots \qquad\qquad \vdots$$

$$a_{n1}x_1 + \ldots + a_{nm}x_m \lesseqgtr b_n$$

$$x_i \geq 0 \qquad (2.3)$$

where

c_j = coefficient of the objective function

x_j = level at which each activity is operated

a_{ij} = coefficient of the constraint equation

b_i = value of the right-hand side

m = number of columns

n = number of rows.

This form can also be translated into the following:

MAX/MIN $\quad Z = CX \qquad (2.4)$

subject to

$$AX \lesseqgtr B \qquad (2.5)$$

$$X \geq 0 \qquad (2.6)$$

where

C = row vector

X, B = column vectors

A = n x m matrix.

FIGURE 2.1. BASIC LP FORMAT

ADAPTING THE STATIC IFRS MODEL TO LP

2.11 A detailed analysis of the Static IFRS methodology was completed as discussed in Section II of Volume I. The results of this analysis are summarized below:

- Training phase resource requirements are linear and can be expressed in terms of student load.
- NAS manpower requirements are linear and total base population can be identified as being either tenant related or training phase related.
- Facility line item requirements can be expressed in terms of amount required per student for the 15 different training phases independent of base. (Note this amount also includes those facilities required by the NAS personnel who support that student.) Also the amount of facility required by the tenants can be estimated separately and is fixed for each base.
- The amount of facilities presently available provides the existing resources.
- An adjusted facilities stock can be calculated that reduces total facility stock by tenant demands.
- The facility investment cost calculations are the only relevant costs to be included in the optimizer since they are the only costs that vary with phase-to-base assignment.
- The facility investment cost calculations are the only relevant costs to be included in the optimizer based on the Static IFRS model.
- These facility investment costs can also be expressed in terms of cost per student for each phase and facility line item.

III. THE MILITARY CONSTRUCTION COST (MCON) MINIMIZER

INTRODUCTION

3.1 The objective of the Military Construction Cost (MCON) Minimizer is to minimize the facility investment cost associated with training a given number of students (PTR) with a given MIX, MODE, and facility inventory. The MCON Minimizer allocates the 15 training phases to the 8 training bases in order to minimize the cost of the new facilities which must be constructed to support the given PTR. Since the MCON Minimizer considers 22 facilities, 8 bases and 15 phases, it is a much larger LP than the PTR Maximizer. In addition, the minimizer has a much more complex form.

3.2 Most LP formulations maximize output, subject to resource constraints, or minimize total cost, subject to required output. The minimizer has a different form; i.e., minimize investment in new facilities, subject to required output and a stock of existing facilities. The problem is not homogenous in that costs are zero throughout a range (i.e., while existing stocks are used) and then rise linearly. Thus, as long as existing facilities will support the pilot training requirements, there is no cost. When all of the existing facilities are exhausted, costs begin to rise. The uniqueness of this formulation will become apparent as the description of the model evolves.

3.3 The MCON Minimizer is a large LP which has 296 terms in the objective function (i.e., 296 columns), 375 constraint rows, and a right-hand (RHS) with 375 terms. The objective function consists of:

- 120 pilot training activity variables
- 176 facility use activities.

The constraint matrix consists of:

- 176 balance equations
- 176 facility stock constraints
- 15 PTR specification equations
- 8 aggregate runway constraints.

The RHS consists of maximum values for each constraint equation.

3.4 Each of these terms is defined in the following paragraphs. Additionally, as an aid to the reader, the MCON Minimizer LP tableau (matrix) is illustrated in Figure 3.1. The reader should refer to this as necessary throughout this discussion. The mathematical formulation of this problem and a sample model formulation appear later in this section. Finally, a discussion on how to interpret the results is included.

OBJECTIVE FUNCTION

Definition of Activities

3.5 Two types of activities are included in the objective function of the LP formulation of the MCON Minimizer.

- The training of students of each phase at each base
- The consumption (or use) of existing facilities at each base.

3.6 The first activity set permits any phase to be located at any base. Thus with 15 phases and 8 bases, 120 terms are required to define it (e.g., the first 15 terms are phases 1-15 assigned to base 1). The second activity set ensures that the value of the objective function is reduced by the replacement cost of the existing facilities stock that was utilized. Thus, it requires 176 terms with 22 facility line items for each of the 8 bases (e.g., terms 121-142 are for the 22 facilities at base 1).

Objective Function Coefficients

3.7 The coefficients of the terms in the objective function are:

- Cost per student to build all new facilities for each phase at each base—the first 120 terms
- The per unit replacement cost of each facility line item at each base—the next 176 terms.

3.8 The cost per student to build all new facilities is the sum of the cost per student over all 22 facility line items. These coefficients are calculated in the appendix, and the current values appear in Table A.8.

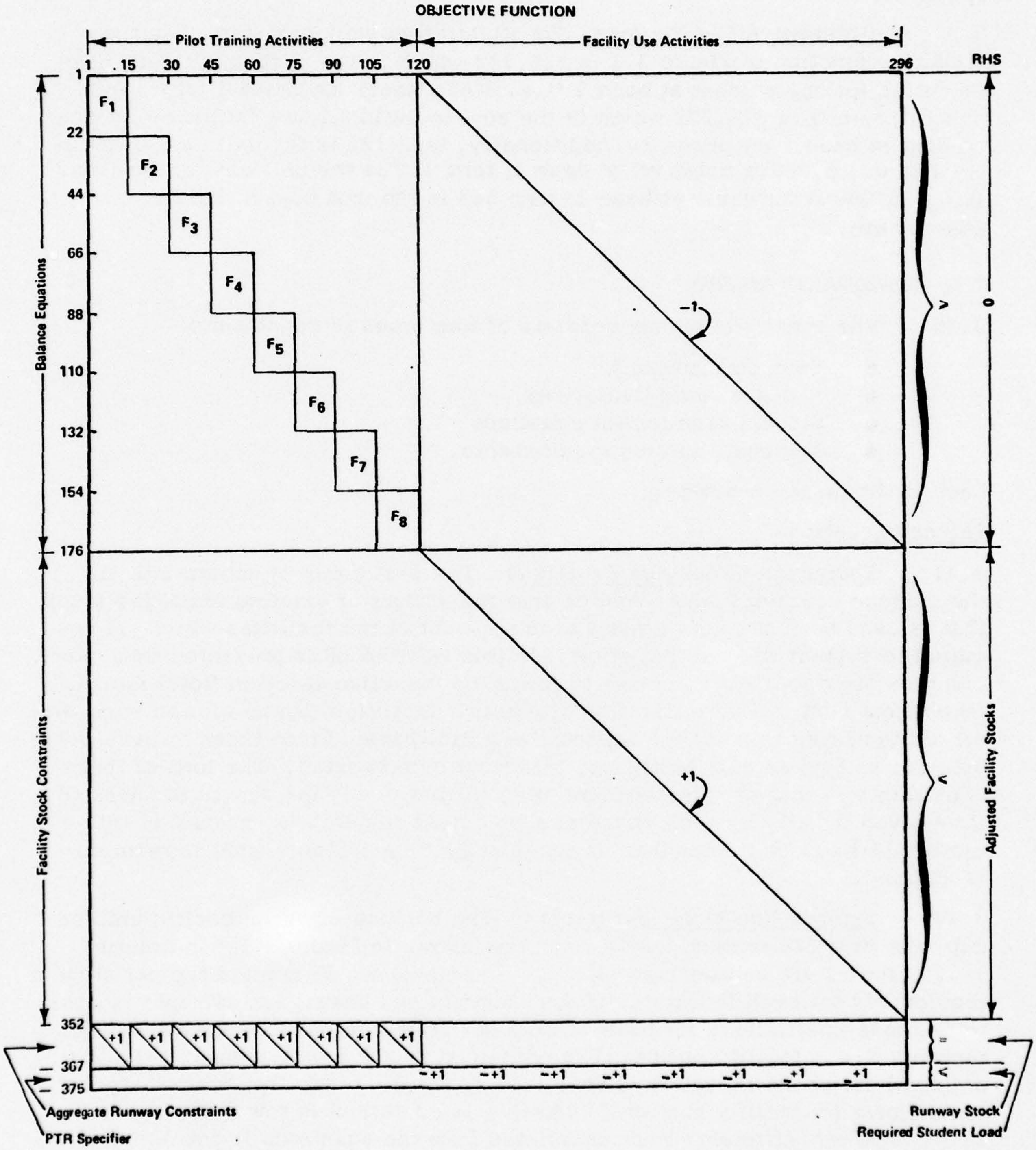


FIGURE 3.1. SCHEMATIC OF MCON MINIMIZER TABLEAU

The unit replacement cost of each facility is included in Table A.4 in the appendix.

3.9 Illustrative Coefficients. For illustrative purposes, term 1 in the objective function of Figure 3.1 is $25,192 which is the cost to build all new facilities for one student at base 1 (i.e., NAS Chase) for phase 1 (i.e., AOC school); term 2 is $24,722 which is the cost to build all new facilities for one student at base 1 for phase 2. Additionally, term 121 is the unit cost of facility 1 (i.e., 3,000 ft runways) at base 1; term 122 is the unit cost of facility 2 (i.e., 5,000 ft runways) at base 1; term 143 is the unit cost of facility 1 at base 2, etc.

THE CONSTRAINT MATRIX

3.10 The constraint matrix consists of four types of constraints:

- Balance equations
- Facility stock limitations
- Student requirement equations
- Aggregate runway requirements.

Each is discussed separately.

Balance Equations

3.11 Definition of Balance Equations. The first group of constraints are the balance equations which require that the amount of existing facilities stock that is used be less than or equal to the amount of the facilities which are required to support the training effort. In this way the LP is prevented from overusing existing facilities in order to lower the objective function (total facility investment cost). Overutilization of existing facilities can be viewed as selling off old facilities to purchase different new facilities. Since there is little possibility of selling surplus facilities, this must be prevented. The form of these constraints is that of "greater than" inequalities; i.e., the sum of the demands for a given facility by each phase at a base less the existing amount of this facility utilized is greater than or equal to 0. That is, only what is required is utilized.

3.12 Balance Equation Coefficients. The balance equation coefficients occupy the first 176 rows of the LP matrix as shown in Figure 3.1. In column 1-120, the Fs are submatrices (balance equations) which contain the per student requirement for each facility by phase, facility and base. For example, F_1 contains these coefficients for base 1. The per student requirement for 3,000 ft runways (i.e., facility number 1) is contained in row 1 and columns 1-15 (i.e., column 1 for phase 1, column 2 for phase 2, etc.). Similarly, the per student requirement for facility number 2 at base 1 is contained in row 2 and columns 1-15. These coefficients were calculated from the equations in the Appendix. These values are contained in Table A.3. In columns 121-296, the matrix also requires that:

$$A_{ij} = -1. \text{ for } i = 1\text{-}176,\ j = 121\text{-}296$$

where

A_{ij} = constraint matrix not including the objective function

i = row number

j = column number.

All other coefficients in this portion of the matrix are zero.

Facility Stock Limitations

3.13 Definition of Facility Stock Limitations. The second group of constraints are the facility stock limitations. These "less than" inequalities place a limit on the stock of existing facilities, net of tenant demands, which can be utilized to offset the demands for facilities required by the training process. These equations state that the amount of existing facilities utilized to offset the training demands are less than or equal to the stock of facilities (net of tenant demands).

3.14 Facility Stock Coefficients. As shown in Figure 3.1, it is necessary to have the following:

$$A_{ij} = 1 \text{ for } i = 177\text{-}352,\ j = 121\text{-}296.$$

All other coefficients in this portion of the matrix are zero.

Student Requirements Equations

3.15 Definition of Student Requirements Equations. The third group of constraints are the student requirements equations. These "equal to" equations drive the LP model and set the output of each training phase. The form of the constraint is that the sum, across all bases, of the students in each phase be equal to a given required student load. Thus these equations reflect PTR and MIX. It should be noted that all 15 phases must be assigned a specified student load. The method of arriving at such a student load is to establish a PTR and MIX and then run the Static IFRS model in order to get the required student load. This student load is then entered into the MCON Minimizer.

3.16 Student Requirements Coefficient. The PTR specification equations (rows 353-367) specify the required student loads across all phases at all bases. Thus, coefficients of these equations are:

$$A_{ij} = 1$$

for

i = 353-367	j = 1-15
i = 353-367	j = 16-30
i = 353-367	j = 31-45

i = 353-367	j = 46-60
i = 353-367	j = 61-75
i = 353-367	j = 76-90
i = 353-367	j = 91-105
i = 353-367	j = 106-120

All other positions in this portion of the matrix have zero coefficients.

Aggregate Runway Constraints

3.17 Definition of Aggregate Runway Constraints. The aggregate coefficients require that the adjusted runway stock for all three runway classes be equal to the adjusted total runway stock. This is accomplished by aggregate runway constraints.

3.18 Aggregate Runway Constraint Coefficient. These eight constraints have the coefficient 1 in the following matrix locations:

Row	Columns
368	121,122,123
369	143,144,145
370	165,166,167
371	187,188,189
372	209,210,211
373	231,232,233
374	253,254,255
375	275,276,277

All other locations have a coefficient of zero.

RIGHT-HAND SIDE

Definition of Right-Hand Side

3.19 The right-hand side (RHS) of the minimizer consists of four groups of values which are associated with the four types of constraints used in the LP.

Right-Hand Side Values

3.20 RHS for Balance Equations. The portion of the RHS associated with the balance equations consists of 176 zeros (i.e., values 1-176) in the form greater than or equal to (i.e., ≥ 0).

3.21 RHS for Facility Stock Limitations. The portion of the RHS associated with the facility stock limitations consists of 176 values (i.e., 22 for each base) which are the adjusted facility stock (i.e., total stock less tenant-generated demand) multiplied by the utilization factor. These are in the form less than or equal to ($\leq$).

For example, RHS value 177 is the adjusted facility stock of the first facility at base 1; RHS value 199 is the adjusted facility stock of the first facility at base 2; etc.

3.22 RHS for Student Requirements Equations. The portion of the RHS associated with the 15 student requirement equations consists of the desired student load for each phase. The RHS values corresponding to the student requirements equations are the required student loads for each phase. These (equal-to) constraints are in the following form:

$$RHS_{353} = \text{required student load phase 1}$$

$$RHS_{354} = \text{required student load phase 2}$$

$$\vdots$$

$$RHS_{367} = \text{required student load phase 15.}$$

3.23 RHS for Aggregate Runway Constraints. The RHS values associated with the aggregate runway constraints (i.e., values 368-375) are the adjusted total runway stock at each base. These are in the form less than or equal to (≤) the adjusted runway stock of all these types of runways at base 1. For example, RHS value 368 is the adjusted runway stock of all three types of runways at base 1.

MATHEMATICAL MODEL FORMULATION—MINIMIZER

3.24 The mathematical formulation of the MCON Minimizer submodel is illustrated in this section. The objective function is defined in equation (3.1) and the constraints in equations (3.2), (3.3), and (3.4) as shown in Figure 3.2.

Sample Model Formulation—Minimizer

3.25 Due to the large size of the MCON Minimizer matrix, it is not practical to present the total model formulation in this report. However, the model formulation is the same regardless of the size of the problem and thus the complete formulation of a smaller sample problem is presented below. In this sample, it is assumed that the manager wants to minimize facility investment cost for two training phases assigned to two bases with two facility line items at each base. The objective function for this problem is defined in equation (3.5) and appears in Figure 3.3. The result of multiplying out this objective function is shown in equation (3.6). Equation (3.7) results from collecting the terms and changing notation. Next the three constraints, equations (3.8), (3.13) and (3.18) appear in Figure 3.4. The LP tableau is shown in Figure 3.5. Once this tableau (matrix) is set up, the LP is run.

$$\text{MIN} \sum_i \sum_j \sum_k C_{ij} (R_{ijk} M_{jk} - X_{ij}) \tag{3.1}$$

Subject to $$\left(\sum_k R_{ijk} M_{jk} \right) - X_{ij} \geq 0 \tag{3.2}$$

$$X_{ij} \leq a_{ij} A_{ij} \tag{3.3}$$

$$\sum_j M_{jk} = SL_k \tag{3.4}$$

where

R_{ijk} = per student demands of the ith facility at the jth base by the kth phase

C_{ij} = unit cost of the ith facility at the jth base

X_{ij} = amount of the stock of the ith facility at the jth base that is used

a_{ij} = usage factor of the ith facility at the jth base

M_{jk} = the student load of the jth base of the kth phase

A_{ij} = the adjusted amount of the ith facility that exists at the jth base

SL_k = the student load of the kth phase

i = facility designator

j = base designator

k = phase designator.

FIGURE 3.2. MCON MINIMIZER FORMULATION

$$\text{MIN } Z = \sum_{i=1}^{2} \sum_{j=1}^{2} \sum_{k=1}^{2} C_{ij} (R_{ijk} M_{jk} - X_{ij}) \tag{3.5}$$

Multiplying this equation results in equation (3.6).

$$\begin{aligned} \text{MIN } Z = {} & C_{11} R_{111} M_{11} + C_{21} R_{211} M_{11} + C_{11} R_{112} M_{12} + C_{21} R_{212} M_{12} + \\ & C_{12} R_{121} M_{21} + C_{22} R_{221} M_{21} + C_{12} R_{122} M_{22} + C_{22} R_{222} M_{22} - \\ & C_{11} X_{11} - C_{12} X_{12} - C_{21} X_{21} - C_{22} X_{22} \end{aligned} \tag{3.6}$$

Collect terms and change notation as shown in equation (3.7).

$$\begin{aligned} \text{MIN } Z = {} & \overbrace{(C_{11} R_{111} + C_{21} R_{211})}^{a_1} \overbrace{M_{11}}^{Z_1} + \overbrace{(C_{11} R_{112} + C_{21} R_{212})}^{a_2} \overbrace{M_{12}}^{Z_2} + \\ & \overbrace{(C_{12} R_{121} + C_{22} R_{221})}^{a_3} \overbrace{M_{21}}^{Z_3} + \overbrace{(C_{12} R_{122} + C_{22} R_{222})}^{a_4} \overbrace{M_{22}}^{Z_4} - \\ & \overbrace{C_{11}}^{a_5} \overbrace{X_{11}}^{Z_5} - \overbrace{C_{12}}^{a_6} \overbrace{X_{12}}^{Z_6} - \overbrace{C_{21}}^{a_7} \overbrace{X_{21}}^{Z_7} - \overbrace{C_{22}}^{a_8} \overbrace{X_{22}}^{Z_8} \end{aligned} \tag{3.7}$$

FIGURE 3.3. MODEL FORMULATION OBJECTIVE FUNCTION

The first constraint is:

$$\sum_{k} R_{ijk} M_{jk} - X_{ij} > 0 \qquad (3.8)$$

Equation (3.8) expands to:

$$R_{111} M_{11} + R_{112} M_{12} - X_{11} > 0 \qquad (3.9)$$

$$R_{211} M_{11} + R_{212} M_{12} - X_{21} > 0 \qquad (3.10)$$

$$R_{121} M_{21} + R_{122} M_{22} - X_{12} > 0 \qquad (3.11)$$

$$R_{221} M_{21} + R_{222} M_{22} - X_{22} > 0 \qquad (3.12)$$

With the new notation, then

$$Z_1 = M_{11}$$

$$Z_2 = M_{12}$$

$$Z_3 = M_{21}$$

$$Z_4 = M_{22}$$

The second constraint is:

$$X_{ij} < a_{ij} A_{ij} \qquad (3.13)$$

Equation (3.13) expands to:

$$Z_5 = X_{11} < a_{11} A_{11} \qquad (3.14)$$

$$Z_6 = X_{12} < a_{12} A_{12} \qquad (3.15)$$

$$Z_7 = X_{21} < a_{21} A_{21} \qquad (3.16)$$

$$Z_8 = X_{22} < a_{22} A_{22} \qquad (3.17)$$

The third constraint is:

$$\sum_{j} M_{jk} = SL_k \qquad (3.18)$$

Equation (3.18) expands to:

$$\overbrace{M_{11}}^{z_1} + \overbrace{M_{21}}^{z_3} = SL_1 \qquad (3.19)$$

$$\overbrace{M_{12}}^{z_2} + \overbrace{M_{22}}^{z_4} = SL_2 \qquad (3.20)$$

FIGURE 3.4. SAMPLE MODEL FORMULATION CONSTRAINTS

$$
\begin{array}{llllllllll}
\text{MIN} & Q_1 Z_1 & + Q_2 Z_2 & + Q_3 Z_3 & + Q_4 Z_4 & - Q_5 Z_5 & - Q_6 Z_6 & - Q_7 Z_7 & - Q_8 Z_8 & \\
\text{Subject to} & R_{111} Z_1 & + R_{112} Z_2 & & & - Z_5 & & & & \geq 0 \\
 & R_{211} Z_1 & + R_{212} Z_2 & & & & - Z_6 & & & \geq 0 \\
 & & & + R_{121} Z_3 & + R_{122} Z_4 & & & - Z_7 & & \geq 0 \\
 & & & + R_{221} Z_3 & + R_{222} Z_4 & & & & - Z_8 & \geq 0 \\
 & & & & & + Z_5 & & & & \leq a_{11} A_{11} \\
 & & & & & & + Z_6 & & & \leq a_{12} A_{12} \\
 & & & & & & & + Z_7 & & \leq a_{21} A_{21} \\
 & & & & & & & & + Z_8 & \leq a_{22} A_{22} \\
 & + Z_1 & & + Z_3 & & & & & & = SL_1 \\
 & & + Z_2 & & + Z_4 & & & & & = SL_2
\end{array}
$$

where

Q_1 through Q_4 = the per student cost of supplying both facilities to students in the 2 phases at the 2 bases

Z_1 = student load of phase 1 students at base 1

Z_2 = student load of phase 2 students at base 1

Z_3 = student load of phase 1 students at base 2

Z_4 = student load of phase 2 students at base 2

Q_5 through Q_8 = the unit costs of the 2 facilities at the 2 bases

Z_5 = amount used of existing facility 1 at base 1

Z_6 = amount used of existing facility 2 at base 1

Z_7 = amount used of existing facility 1 at base 2

Z_8 = amount used of existing facility 2 at base 2

FIGURE 3.5. SAMPLE MODEL FORMULATION LP TABLEAU

$\alpha_{11}A_{11}$ = adjusted facility stock of facility 1 at base 2

$\alpha_{11}A_{12}$ = adjusted facility stock of facility 2 at base 2

$\alpha_{21}A_{21}$ = adjusted facility stock of facility 1 at base 2

$\alpha_{22}A_{22}$ = adjusted facility stock of facility 2 at base 2

and the Rs are the per student requirements of the 2 facilities at the 2 bases by the 2 phases, e.g., R_{221} is the requirement per student in phase 1 for facilities of type 2 at base 2.

SL_1 = required student load of phase 1

SL_2 = required student load of phase 2.

FIGURE 3.5 (Cont)

INFORMATION PROVIDED BY THE MINIMIZER

3.26 This submodel provides a variety of planning information depending on the printout option selected. Each option requires a different printing time. The first level of information in the minimizer is a printout of the objective function. This printout provides the optimal phase-to-base assignment, the student load by phase at each base, and the amount of existing facilities used by facility and base. The second level of information includes the shadow prices which provide the marginal cost of training a student by phase and base. The third level of printout includes the LP matrix which provides the amount of new facilities constructed by facility and base and the amount of unused facilities by facility and base. Note that a printout of the investment cost minimizer's final matrix involves printing about 260,000 values, which might take up as much as 900 pages of computer output; thus, this output option should be used sparingly.

Interpretation of Results for Information Level 1—Minimizer

3.27 Once the LP model is run and an optimal solution is obtained, the results are as follows:

- The number of students of each phase at each base (i.e., the optimal phase-to-base assignment) are the objective function.
- The amount of existing facilities utilized for pilot training is the value of terms 121-296 of the objective function (i.e., 22 values for each base in the order of the facility numbers and base numbers).
- The excess facilities remaining appear as the row values for rows 177-352 once optimality is reached.
- The total facility investment cost is the final value of the objective function.

TESTING THE OPTIMIZATION MODEL

3.28 Since the MCON Minimizer calculates facility investment cost, excesses, and deficiencies as well as solving for an optimal phase-to-base assignment, it is possible to check the results of the MCON Minimizer. The procedure for checking is to use the phase-to-base assignment provided by the MCON Minimizer as an input to the Static IFRS model. Next, run the Static IFRS model and compare results.

Closeness of Results

3.29 Although the MCON Minimizer handles runways in a different manner than the Static model, and the facilities requirements equations of the MCON Minimizer are somewhat different, the results of the test run were very close.

With only minor exceptions the MCON Minimizer indicated the same number and amount of facility deficiencies as did the Static model for those facilities included in the MCON Minimizer. This indicates that the formulation of the MCON Minimizer is correct.

Total MCON Investment Cost

3.30 Since the MCON Minimizer does handle runways differently than the Static model, and since the Static model contains facilities which are not included in the MCON Minimizer (e.g., ineligible family housing, aircraft operations buildings), the total MCON investment cost is best calculated through use of the Static model.

3.31 The test run revealed that based on a 2,245 PTR, the phase-to-base assignment provided by the MCON Minimizer resulted in a savings in facility investment cost of approximately $2 million over the present phase-to-base assignment.

IV. THE PILOT TRAINING RATE (PTR) MAXIMIZER

INTRODUCTION

4.1 The objective of PTR Maximizer submodel is to maximize the student output of the pilot training program given certain facility constraints. These facility constraints are the current stock of the crucial facilities at each base plus expected additions to the stock due to construction. The PTR Maximizer allocates the 15 training phases to the 8 bases in a manner that maximizes PTR for these constraining facilities. The PTR Maximizer does not consider all facilities to be constraining, because, realistically, the stock of a facility such as automobile parking areas, cannot be viewed as placing a limitation on the number of students who can be trained. Thus the analyst must select that group of facilities which actually puts a limit on the number of students. Such facilities might be aircraft-oriented facilities such as runways, taxiways, aircraft parking aprons, hangars, etc. An alternative list might include personnel-oriented facilities such as family housing, BOQs, exchanges, enlisted men's barracks, etc. The selection of the appropriate facility group is the responsibility of the user and will be determined largely by the user's specific analytic needs.

4.2 Presently this submodel is set up to include six different facilities in each run. The PTR Maximizer is a much simpler formulation than the MCON Minimizer. It is a standard LP problem of maximizing output subject to resource constraints and a specified MIX of outputs.

4.3 There are 120 terms in the objective function, (i.e., 120 columns), 62 rows in the matrix (i.e., 6 facilities times 8 bases plus 14 rows to define student MIX), and 62 terms in the RHS.

The objective function consists of:

- 120 pilot training activity variables.

The constraint equations consist of:

- 48 facility requirements equations
- 14 MIX specification equations.

The RHS consists of maximum values for each constraint equation. Each of these terms is defined in the following paragraphs. As an aid to the reader, a schematic of the PTR Maximizer tableau (i.e., matrix) is shown in Figure 4.1. The reader should refer to this figure as necessary throughout the discussion. The mathematical formulation of this problem and a sample model formulation appear later in this section. Finally, a discussion on how to interpret the results is included.

OBJECTIVE FUNCTION

Definition of Activities

4.4 The activities included in the PTR Maximizer objective function are the training of students of each phase at each base. This permits any phase to be located at any base. Thus with 15 phases and 8 bases, 120 terms are required to define it (e.g., the first 15 terms are phases 1-15 assigned to base 1).

Objective Function Coefficients

4.5 In this submodel each term has the coefficient value of 1.

THE CONSTRAINT MATRIX

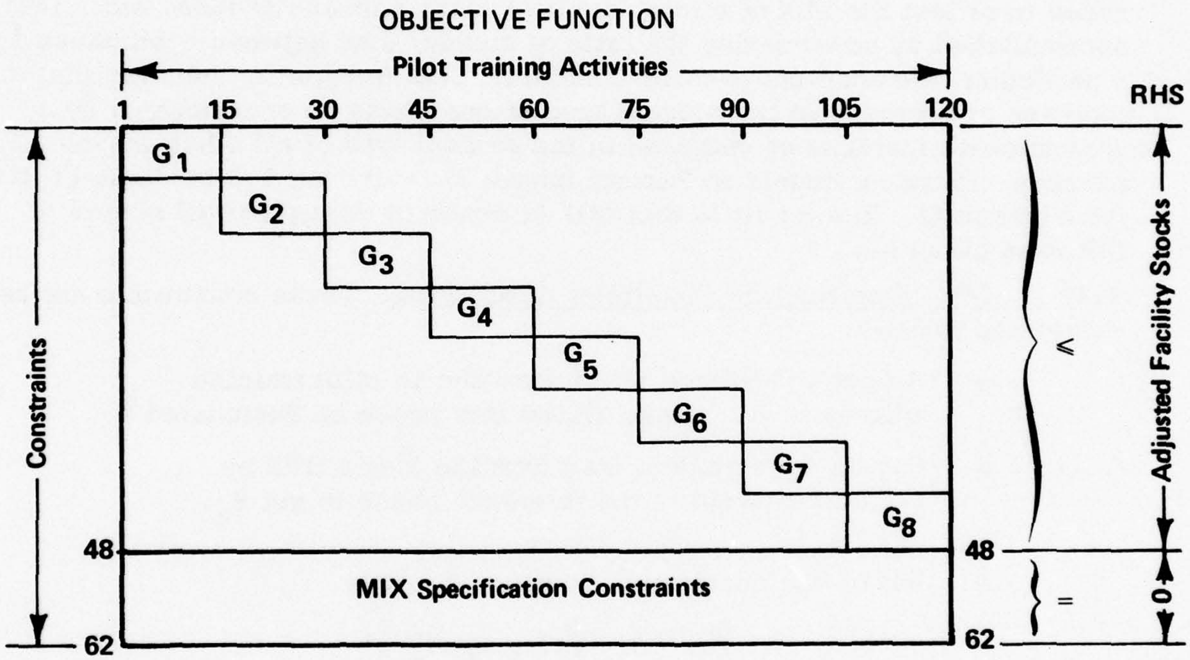
4.6 Two types of constraints are required in the PTR Maximizer:

- Facility requirements
- MIX specifications.

Facility Requirements Constraints

4.7 Definition of Facility Requirements Constraints. The facility requirements constraints dictate that the amount of facilities required be less than or equal to the adjusted facilities stock of each base. In this way the LP can utilize only those facilities specifically available for pilot training.

4.8 Facility Requirements Constraints Coefficients. These coefficients are identical to the diagonal submatrices (the Fs) in the MCON Minimizer except that the number of facilities considered in each submatrix is 6 (versus 22 in the MCON Minimizer). This reflects the fact that the pilot training process cannot be viewed as being constrained by relatively less important facilities. The



Note a. The Gs are the same as the Fs of the minimizer except 6 facilities are considered in this example.

Note b. The form of the MIX specification constraints depends upon the choice of the reference phase.

FIGURE 4.1. SCHEMATIC OF THE PTR MAXIMIZER TABLEAU

coefficients of these constraints are developed in the appendix and are the per student requirements for the selected constraining facilities shown in Table A.3. For example: term 1 in equation 1 is the per student requirement for facility 1 by phase 1 at base 1. These are the same coefficients used in the balance equations of the MCON Minimizer.

MIX Specification Constraints

4.9 Definition of MIX Specification Constraints. Constraints must also be added to reflect the MIX of pilots, attrition rates between phases, etc. This is accomplished by constraining the ratio of student load between each phase and a particular reference phase to be constant. This formulation requires that an increase or decrease in the student load of one phase be accompanied by a proportionate increase or decrease in the student load of all other phases. For example: for each student in Primary (phase 3), there are 1.3 students in Basic Jet A (phase 4). The result is that MIX is constant throughout all ranges of PTR for a given run.

4.10 MIX Specification Constraint Coefficient. These constraints are calculated as follows:

- Select a reference phase from the 15 pilot training phases (e.g., phase 3), let this phase be designated $\bar{k}$.
- Divide each student load from the Static IFRS by the student load in the reference phase to get B_k.
- Set up the constraint equations so that:

$$\sum_{j=1}^{8} P_{kj} - \sum_{j=1}^{8} B_k P_{\bar{k}j} = 0$$

where

$\bar{k}$ = the phase number of the reference phase

P_k = student load in phase k.

These constraints require that the ratio of student loads to each other be constant over all PTR, thus specifying MIX.

RIGHT-HAND SIDE

Definition of Right Hand Side

4.11 The right-hand side (RHS) consists of two groups of values which are associated with two types of constraints.

Right-Hand Side Values

4.12 RHS for Facilities Requirements Equation. The values of the RHS associated with the facility requirements are the adjusted facility stocks (i.e., total stock less tenant-generated demands) multiplied by the facility utilization factor.

4.13 These "less than" constraints place a limit upon the total number of students who can be trained at each base. The values of these terms are identical with the values of the facility stock RHS in the minimizer except that fewer facilities are included. These adjusted tenant demands are developed in the appendix and appear in Table A.7.

4.14 RHS for MIX Specification. The last 14 terms of the RHS are associated with the "equal to" MIX specification and each has a zero value.

MATHEMATICAL MODEL FORMULATION—MAXIMIZER

4.15 The mathematical formulation of the PTR Maximizer submodel is presented in this section. The objective function is defined in equation (4.1) and the constraints in equations (4.2) and (4.3) as shown in Figure 4.2.

Sample Model Formulation—Maximizer

4.16 For illustrative purposes, assume the manager wants to maximize PTR for a two-base, two-phase, two-facility training program. The objective function for this problem is defined in equation (4.4).

$$MAX = Z_1 + Z_2 + Z_3 + Z_4 \tag{4.4}$$

where

Z_1 = student load of phase 1 at base 1

Z_2 = student load of phase 2 at base 1

Z_3 = student load of phase 1 at base 2

Z_4 = student load of phase 2 at base 2.

The preceding objective function is subject to the constraints of equations (4.5) through (4.9).

$$\begin{array}{lllll}
R_{111}Z_1 + R_{112}Z_2 & & & & \le \alpha_{11}A_{11} \\
R_{211}Z_1 + R_{212}Z_2 & & & & \le \alpha_{21}A_{21} \\
 & & R_{121}Z_3 + R_{122}Z_4 & & \le \alpha_{12}A_{12} \\
 & & R_{221}Z_3 + R_{222}Z_4 & & \le \alpha_{22}A_{22} \\
B_1Z_1 & - Z_2 & + B_1Z_3 & - Z_4 & = 0
\end{array}$$

where

R_{111} = amount of facility 1 required by a student at base 1 in phase 1

R_{112} = amount of facility 1 required by a student at base 1 in phase 2, etc.

B_1 = MIX ratio between student load in phase 1 to phase 2 with phase 2 taken as the reference phase

α_{11} = facility utilization factor for facility 1 at base 1

α_{21} = facility utilization factor for facility 2 at base 1, etc.

A_{11} = adjusted stock of facility 1 available (net of tenant demand) at base 1

A_{21} = adjusted stock of facility 2 available (net of tenant demand) at base 1, etc.

INFORMATION LEVELS PROVIDED BY THE MAXIMIZER

4.17 The submodel can provide a variety of planning information, depending upon the output option selected. Each option takes a different length of time to print out. The first level of information is a printout of the objective function. This printout provides the optimal phase-to-base assignment, the student loads at each base, the amount of excess facilities at each base and an indication of which facilities are constraining at each base (indicated by zero amount of excess facility). The next level of information includes the shadow prices of the resources selected to be constraining. The shadow prices determine the marginal contribution to pilot output of one additional unit of each resource (i.e., facility). The third level of output includes a printout of the final LP matrix. This determines the amount of each facility that is utilized in the pilot training process.

Interpretation of Results, Information Level 1, PTR Maximizer

4.18 Once the LP model is run and optimal solution is obtained, the results are as follows:

- The number of students of each phase at each base (i.e., the optimal phase-to-base assignment) are the first 120 values of the objective function. These values can be translated directly into the PTR.
- The units of facilities not used (i.e., excesses) are the value of the slack variable in terms 125-168 of the objective function.

$$\text{MAX}_j \sum_k M_{jk} \tag{4.1}$$

Subject to

a. $\sum_k R_{ijk} M_{jk} \leq \alpha_{ij} A_{ij}$ (4.2)

b. $\sum_j M_{j,1} \quad = B_1 \sum_j M_{j\bar{k}}$ (4.3)

$$\begin{matrix} \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \end{matrix}$$

$\sum_j M_{j,n} \quad = B_n \quad \sum_j M_{j\bar{k}}$

where

M_{jk} = number of phase k students at base j

B_k = factor to represent MIX ratio $(P_k/P_{\bar{k}})$

α_{ij} = facility utilization level of the ith facility at the jth base

A_{ij} = adjusted amount of facility i at base j left after satisfying tenant demands

R_{ijk} = per student demand of ith facility at the jth base by the kth phase

i = facility designator

j = base designator

k = phase designator.

FIGURE 4.2. MATHEMATICAL FORMULATION OF THE PTR MAXIMIZER SUBMODEL

V. COMPUTER USAGE AND PROGRAM INSTRUCTIONS

5.1 Both optimization submodels have been tested and debugged and are ready for further use. Each submodel uses a different LP package as well as a different computer system. The computer card decks must be set up in the proper order. This section discusses how each deck is set up. Those changes required to modify coefficients are also discussed.

THE PTR MAXIMIZER SETUP

5.2 The PTR Maximizer submodel is run with an LP package developed by ORI. This LP package, LPROG, is quite efficient for problems consisting of less than 80 rows and 120 columns and has been used successfully in other types of LP problems. This submodel is presently operational on ORI's CDC 3100 computer.

5.3 This program is very efficient for small programs (run time is short); however, because of roundoff errors and core requirements, it is only efficient when a maximum of six facilities is considered constraining. This program deck and the input data cards for the six constraining facility problems will be submitted to NAVFAC. It should be noted that the maximizer can also be set up to run on the NAVCOSSACT 1108 system with little effort.

5.4 Program Compilation. The program is written in FORTRAN IV and can be used on any computer with a FORTRAN IV compiler. It is necessary to compile the source program for each machine configuration and approximate problem size. This is necessary, since any problem up to the compiled size may be run and only that part of the reserved memory area (i.e., core) is used.

5.5 The first source statement of the program is a common statement with A(I,J), W(I), L(I), XM(J). To change problem size, these dimensions must be changed and the program recompiled. The preceding subscripts are defined as follows:

I = number of bases x number of facilities considered in this run + 16

J = number of phases x number of bases + number of facilities x number of bases + 1.

5.6 Data Input Mode. A sample card deck setup appears in Figure 5.1. The data input required is discussed below.

a. Header card

Card Column	Value
1-4	I-1
5-8	J
9-28	-1.

b. Objective function—one card for each term

Card Column	Value
1-4	0
5-8	Column index of objective function variable
9-28	-1.

c. Matrix elements (including slack variables)—one card for each element

Card Column	Value
1-4	Row number of element in matrix
5-8	Column number of element in matrix
9-28	Value of element in matrix (only nonzeros needed).

d. Blank card

e. Right-hand side—one card for each element

Card Column	Value
1-4	Row number of equation
5-8	(1) 0, if equation for that row is a MIX specification equation (2) If equation is a facility stock variable, the column index of slack variable associaated with that constraint
9-28	Value of right-hand side element (only positive RHS values allowed).

f. Blank card.

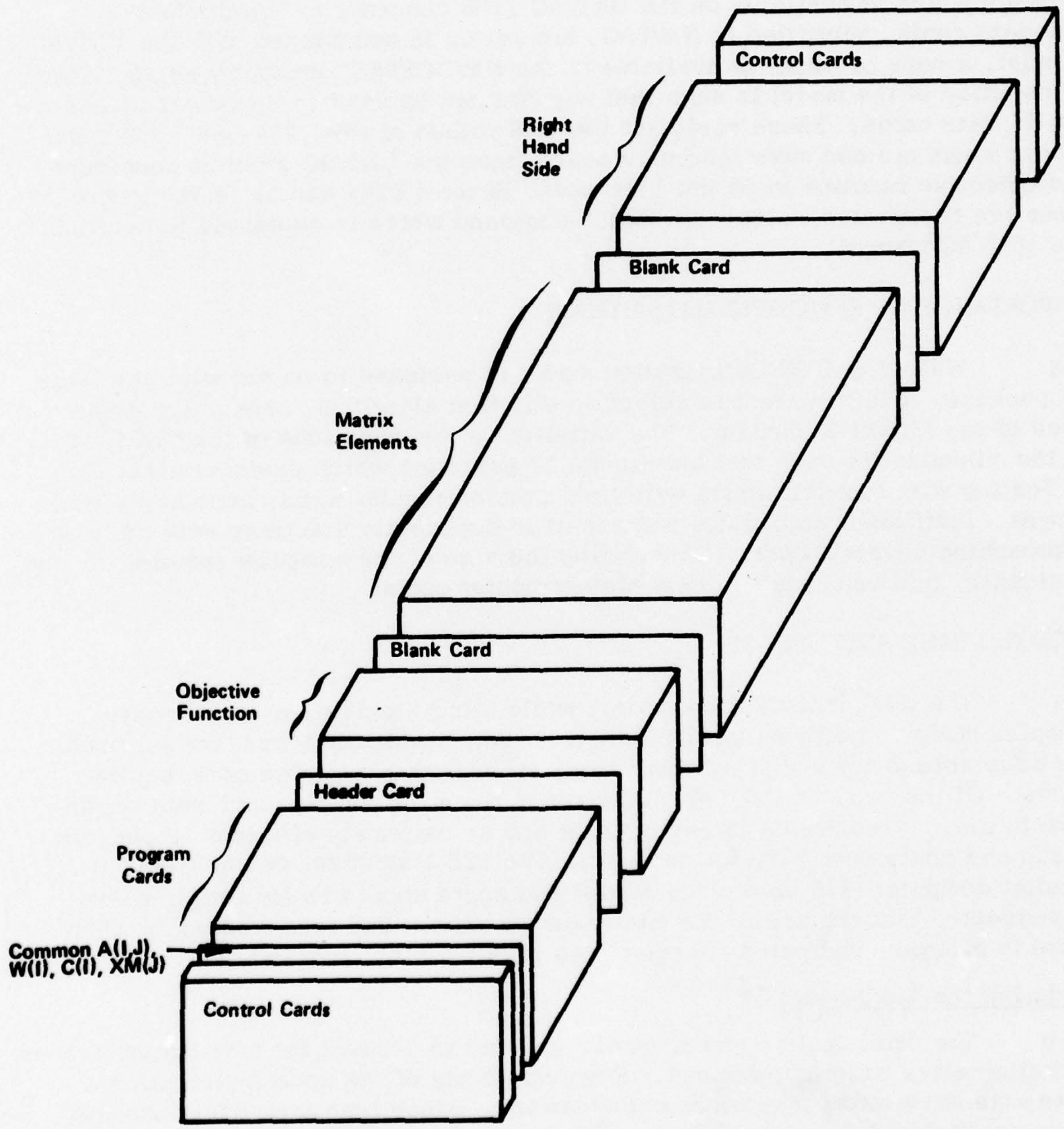


FIGURE 5.1. CARD SETUP FOR PTR MAXIMIZER

THE MCON MINIMIZER SETUP

5.7 The MCON Minimizer submodel is set up to run with UNIVAC's LP package which is available on the UNIVAC 1108 computer at NAVCOSSACT. The data cards, submitted to NAVFAC, are set up in accordance with the UNIVAC manual, a copy of which is available at the NAVCOSSACT computer center. The formulation of the model is such that any PTR can be used in the model by changing 15 data cards. These cards set the RHS values of rows 354-368 (note these row numbers are one more than previously since the UNIVAC program considers the objective function to be the first row). Several PTRs can be tested in the same run though use of the "NORMAL" command which is explained in detail in the UNIVAC manual.

IMPORTANCE OF EFFICIENT ALGORITHMS

5.8 While the IFRS Optimization model is designed to be run with any large LP package, it is important to select an efficient algorithm, especially in the case of the MCON Minimizer. The variation in the magnitude of the coefficients of the minimizer is such that only those LP packages which exercise great care in dealing with roundoff errors will yield precise results within acceptable time frames. Inefficient algorithms may result in degenerate solutions with run times approaching several hours. Considering the size of the computer required for the minimizer, this can result in very high computer costs.

MODEL USAGE AND UPDATE

5.9 The IFRS Optimization model, while fairly flexible, is an extremely complex model. Neither the PTR Maximizer nor the MCON Minimizer submodels are adaptable to time-sharing computers, since both have large core requirements. Of the two, the MCON Minimizer is the most complex and most expensive to run. It requires a large computer and an extremely efficient LP package to run and costs over $200 for each run. The PTR Maximizer can be run on a smaller computer (32K core size and up) and costs about $15 for each run. It is suggested that the use of the minimizer be limited and runs made only when there is a large anticipated change in the pilot training program.

Updating the Model

5.10 The Optimization model can be updated to account for new circumstances and alternative training programs. However, some of the updating requires a more extensive effort than other modifications. Since both submodels use the same coefficients for optimization, with the exception of the equations dealing

with PTR and MIX, the comments on updating are the same for both models except as noted. The possible changes in circumstances which would affect the model are:

- Changes in PTR
- Changes in MIX
- Changes in facility stocks
- Changes in tenant population
- Changes in syllabus or pilot training planning factor
- Changes in facility unit costs
- Changes in pipeline
- Changes in facility planning factors.

5.11 Changes in PTR. A change in PTR can be readily included in the minimizer by changing the values of the RHS associated with the student requirements equations. No change is needed for the PTR Maximizer since that submodel solves for a maximum PTR.

5.12 Changes in MIX. A change in MIX can be handled in the same fashion as a change in PTR in the MCON Minimizer. A change in MIX requires changing the coefficients of the MIX equations in the PTR Maximizer.

5.13 Changes in Facility Stocks. Changes in facility stocks can be reflected by increasing, or decreasing the value of the RHS elements associated with facility stocks in both models.

5.14 Changes in Tenant Population. Changes in tenant population require the recalculation of the tenant demand equations in the appendix and the subsequent recalculation of the adjusted facility stocks which comprise the value of the RHS element associated with facility stocks.

5.15 Changes in Syllabus or Pilot Training Planning Factors. Changes in syllabus require the recalculation of the facility requirements equations in the Appendix and the inclusion of these new values in the LP matrix. This change also requires a recalculation of the first 120 terms of the objective function. Such a change is quite extensive for the MCON Minimizer and requires the preparation of several thousand new data cards for the LP program. The changes in the PTR Maximizer are less extensive due to the smaller number of facilities considered in this submodel.

5.16 Changes in Facility Unit Costs. A change in facility unit costs requires the recalculation of the terms in the objective function. The number of terms which change are eight times the number of facilities whose unit costs have changed plus 120. While this is an extensive modification requiring the calculation of a large number of values, it is not too difficult.

5.17 <u>Changes in Pipelines.</u> The pipelines can be changed relatively easily in the minimizer by changing the RHS values of the student load requirements equations. Changing the pipeline in the PTR Maximizer involves the same changes as does a change in MIX.

5.18 <u>Changes in Facility Planning Factors.</u> This change would require a complete recalculation of the matrix, the RHS, the tenant demands, the facility requirement equations and the objective function. Such a change involves all of the changes required by changes in syllabus plus those changes required by changes in tenant population and facility unit costs.

APPENDIX

FUNCTIONAL RELATIONSHIPS AND COEFFICIENTS

This appendix contains a detailed description of the calculations required to prepare the factors (i.e., coefficients) required to set up the optimization submodels. The primary data source is the Static IFRS model. Essentially there are two groups of coefficients:

- Pilot training factors
- Facility cost and tenant factors.

The development of each of these factors and sample calculations are discussed.

PILOT TRAINING FACTORS BY PHASE

Factors derived from the LSR module of the Static IFRS model express resource requirements in terms of student load. The factors are:

a. Phase officers per student (PO/S)

b. Phase enlisted men per student (PE/S)

c. Total phase personnel per student (PP/S)

d. Phase aircraft per student (AC/S)

e. Annual fuel requirement per student (AF/S)

f. Runways per student (R/S).

These factors were computed by dividing the total of each requirement for each phase by the student load for each phase. Both the resource requirements (i.e., officers, enlisted men, aircraft and fuel) and the student load for each phase were calculated by the LSR module of the Static IFRS model. Since the functional

relationships in the LSR module are linear, these factors are also linear and do not change as PTR and MIX change. However, a change in MODE or in the pilot training planning factors necessitates recalculating these factors.

In this manner, the LSR module drives the Optimization model just as it drives the Static IFRS model. The current values for these factors are given in Table A.1.

Example:

Phase 7 Adv Jet TF

Student load 151.9

Total officers in phase 167

Calculate PO/S, i.e., phase officer per student, to be

$$\frac{167}{151.9} = 1.142.$$

FACILITY REQUIREMENT FACTORS BY BASE

All of the facility requirements, with the exception of aircraft parking aprons, are calculated with average factors. This causes these per student facility requirements for a given phase to be constant over all bases. Thus there are 15 separate calculations per facility (i.e., one per phase) with the exception of aircraft parking aprons. The peculiar characteristics of aircraft parking aprons, however, require that a separate requirement be calculated for each phase at each base.

The next section of this appendix contains the detailed derivation of each facility requirement. Tables A.3-A.9 contain the relevant facility data for the Optimization model and appear at the end of this appendix.

TABLE A.1

FACTORS DERIVED FROM LSR GENERATOR

Phase	Factors					
	PO/S	PE/S	PP/S	AC/S	AF/S	R/S
1	.030	0	.030	0	0	
2	.032	0	.032	0	0	
3	.526	1.009	1.534	.329	3.349	.002688
4	.639	2.362	3.002	.376	81.775	.003174
5	.851	5.000	5.851	.602	144.669	.003884
6	.627	4.244	4.871	.482	92.861	.004225
7	1.142	6.788	7.931	.837	290.334	.007747
8	1.093	6.098	7.192	.738	275.743	.007751
9	.552	2.266	2.819	.438	15.561	.001971
10	.394	2.019	7.413	.295	9.408	.003315
11	.807	4.695	5.503	.456	35.011	.004170
12	.560	2.300	2.870	.440	15.890	.000621
13	.470	1.690	2.170	.270	11.850	.002392
14	.640	1.580	2.220	.440	3.810	.009457
15	.870	4.060	4.930	.570	35.530	.005324

MODEL DERIVATION

Category Code: 110-10, 110-20, 112-10, 112-11, 112-12 (112-80), 131-30

Facility: Runways, Taxiways, Runway Lighting

Facility No: 1, 2, and 3

Definition of Facility:

Runways, taxiways, and runway lighting include the complete runway system. For the purposes of the Optimization model, these are built as a unit.

Assumptions:

a. Existing runways have adequate taxiways and lighting.

b. Existing crosswind runways satisfy the crosswind requirements generated by primary runways. Runway stock is adjusted to reflect this assumption.

c. No runway upgrading is allowed.

d. Runways are built in pairs, i.e., a runway system.

e. Tenant demands on runways are zero.

Runway Types:

Three runway types are used in the Optimization model:

a. 3,000 ft bituminous runway

b. 5,000 ft Portland cement runway

c. 8,000 ft Portland cement runway.

Example of Adjusting Runway Stock:

Chase Field has two 8,000 ft primary runways and one 6,000 ft crosswind runway. The adjusted facility stock is then two 8,000 ft runways. Table A.2 shows the adjusted runway stock for each base.

Since runways are built in pairs, the cost for each runway system will be twice the cost which was used in the Phase II Static model (i.e., the cost of one primary and one crosswind).

NAVFAC's P-80 facility requirements document states that a runway system must have 95% wind rose coverage. Therefore, the runway requirement for students must be factored up to reflect the average 5% of the time that the runway is down due to wind conditions. These figures are included in Table A.2.

Since runway length required varies by phase (i.e., type of aircraft) and since requirements for short runways can be satisfied by long runways,

TABLE A.2

ADJUSTED RUNWAY STOCK

Base	Runway Stock		
	3,000 ft	5,000 ft	8,000 ft
Chase			2
Corpus Christi		2	1
Ellyson	3		
Kingston			2
Meridian			2
Pensacola			1
Saufley		2	
Whiting		2	

each runway type is considered to be a separate facility. This is accounted for by increasing the available amount of each type runway by the sum of the number of runways of that length plus the number of runways of longer lengths. Then the total number of runways can be constrained to be equal to the total number at the base. This formulation is illustrated below, using Corpus Christi as the sample NAS:

Adjusted runway stock

Two 5,000 ft Portland cement runways

One 8,000 ft Portland cement runway

Adjusted amount of type 1 (3,000 ft) runways = 3

Adjusted amount of type 2 (5,000 ft) runways = 3

Adjusted amount of type 3 (8,000 ft) runways = 1

Total available = 3

This formulation allows long runways to satisfy the requirements for shorter runways. It also protects against overutilization of the existing runways.

Sample LP Format for Runway Availability

$$X_1 \leq 3$$

$$X_2 \leq 3$$

$$X_3 \leq 1$$

$$X_1 + X_2 + X_3 \leq 3$$

Table A.3 shows the adjusted runway requirements and Table A.4 shows the associated costs for each phase. (Tables A.3-A.9 appear at the end of this appendix.)

Example:

Phase Adv Jet TF

Student load 151.9

Number of runways required from LSR Module 1.18

Runway uptime due to wind .95

$$\frac{1.18}{151.9} = .007747$$

$$\frac{.007747}{.95} = .008155 = \text{runway required/student.}$$

MODEL DERIVATION

Category Code: 113-20, 113-21, 113-22, (113-81)

Facility: Aircraft Parking
Facility No: 4

Definition of Facility:

The aircraft parking apron area is divided into two distinct categories:

a. Actual aircraft parking apron area includes only the area on which aircraft are parked, including spacing factors and taxiways between rows and columns, but excluding peripheral taxiways.

b. Paved peripheral taxiway areas surround the actual aircraft parking apron.

These two categories are combined to get total paved aircraft parking area requirements.

Calculation of Requirement:

The methodology for calculating aircraft parking apron is developed from the Phase II methodology for this facility. Tenant demands for parking area are calculated as a function of the tenant aircraft plus the station aircraft assigned to a base. Tenant demands for aircraft parking apron also include the requirement for the fixed component of the peripheral taxiways (the ends).

Adjusted Tenant Requirements:

The equation for the tenant demand for aircraft parking apron is:

$$TPA_i = \sum_{t=1}^{n} \frac{1}{9} \left(\frac{(AC_{it})(A_t + D_t)(C_t)(AD_i + 2TD_i)}{(AD_i - B_t)} - (D_o)(AD_i + 2TD_i) + (AD_i + 2TD_i)(2TD_i) \right)$$

where

TPA_i = total tenant requirements for aircraft parking apron at base i

AD_i = depth of parking area (excluding two peripheral taxiways of depth TD_i each) at base i

AC_{it} = number of tenant aircraft of type t at base i

C_t = depth requirement (including internal taxiway) per aircraft of type t

B_t = depth requirement (excluding internal taxiway) per aircraft of type t

TD_i = peripheral taxiway width at base i

A_t = width requirement per aircraft of type t

D_t = between aircraft taxiway width requirement per row of aircraft of type t

D_o = taxiway width requirement for the smallest aircraft type to utilize the parking apron

n = number of aircraft types t assigned to base i.

Per Student Requirements:

The per student requirements for aircraft parking apron are:

$$SPA/s_p = \frac{1}{9}\left(\frac{(AC/s_p)\,(A_t + D_t)\,(C_t)\,(AD_i + 2TD_i)}{(AD_i - B_t)}\right)$$

where

SPA/s_p = per student aircraft parking area requirements for students in phase p

AC/s_p = per student requirement for aircraft associated with phase p

and AD, TD, A, B, C, D are as previously defined.

Example:

Phase 7 Adv Jet TF

Base: 1 (i.e., Chase)

AD = 250

TD = 150

For TF 9J's:

A = 34.5

B = 34.5

$C = 68.0$

$D = 90.0$

For Phase 7 $AC/s_7 = .837$.

Thus

$$SPA/s_7 = \frac{1}{9}\left(\frac{(.837)\,(34.5 + 90)\,(.68)\,(250 + 300)}{(250 - 34.5)}\right) = 2009.6.$$

Table A.5 contains the per student requirements by base and phase for aircraft parking apron. Table A.6 contains the cost per student, and Table A.7 contains the tenant requirement by base for aircraft parking apron.

Source of Independent Variables:

AD_i—stored in base data file

A_t, B_t, C_t, D_t—obtained from NAVFAC P-80 and stored in aircraft data file

AC_{it}—data from the Base Loading submodel and the base data file (for tenant aircraft)

TD_i—stored in facilities requirements program.

MODEL DERIVATION

Category Code: 124-30

Facility: Aircraft Ready Fuel Storage Tank

Facility No: 5

Definition of Facility:

Aircraft ready fuel storage tanks are defined for air installations to be all aviation fuel storage tanks for three fuel types—jet, aviation gas, and helo fuel, whether the tanks are located on, adjacent to, or remote from the base. In the Optimization model, ready fuel storage was calculated for all fuel types and not separated out by jet, prop or helo.

Calculation of Requirement:

The ready fuel storage requirement for each type of fuel on a base depends on three factors: (a) the number of days' supply of fuel required to be stored; (b) the percent of fuel which is lost in storage, and (c) the annual amount of fuel to be used.

Adjusted Tenant Requirements:

$$TBFS_i = \left(\frac{TF_i}{365}\right)(PF)(1 + EL)$$

where

$TBFS_i$ = ready fuel storage requirement for fuel at base i

PF = number of days supply required to be stored

EL = efficiency of loss factor for fuel at base

TF_i = annual bulk fuel requirements for all tenant users at base i.

Per Student Requirements:

$$SBFS_p = \left(\frac{AF/s_p}{365}\right)(1 + EL)(PF)$$

where

AF/s_p = annual bulk fuel requirements per student for students in phase p

$SBFS_p$ = per student requirement for ready fuel storage by students in phase p.

Example:

$$SBFS_p = \left(\frac{290334}{365}\right)(10)\,(1.11) = 8829$$

assuming

efficiency loss of 11%

10 days fuel required

per student requirement for fuel = 290,334.

Table A.3 gives the per student requirements for ready fuel storage by phase and Table A.4 shows the cost per student. The ready fuel storage requirements by the tenants at each base appears in Table A.7.

Source of Independent Variables:

PF_{if}—stored in the base data file

EL_{if}—stored in the base data file

AF/s_p —calculated earlier

TF_{if}—calculated in the Base Loading submodel.

MODEL DERIVATION

Category Code: 125-40

Facility: Distribution Pipeline Underground

Facility No: 6

Definition of Facility:

Distribution lines (fuel) are defined as the total length of pipelines required to distribute fuel from all ready fuel storage facilities at an installation. The requirement is assumed to include provisions for valves, covering, fittings, trenching, backfilling, and cathodic protection when required. Lines may be above or below ground, although the latter is preferred where possible.

Calculation of Requirement:

The estimated miles of fuel distribution pipeline required by a naval air station have been derived using regression analysis in Phase II to obtain the length of pipe required as a function of the total number of tenants and squadron personnel stationed at a base.

Adjusted Tenant Requirements:

$$TDP_i = .001375\ (TP_i)$$

where

TDP_i = miles of distribution pipeline required by tenants at base i

TP_i = total number of tenant personnel on base i.

Per Student Requirements:

$$SDP_p = .001375\ (SP/s_p + 1)$$

where

SDP_p = per student requirement for distribution pipeline by students in phase p

SP/s_p = ratio of phase personnel to student load.

Example:

Phase 7 Adv Jet TF

$SP/s_7 = 7.931$

$SDP_7 = .001375\ (7.931 + 1) = .0123$

Tables A.3, A.4, and A.7 contain the results of these equations for each phase and base.

Source of Independent Variables:

SP/s_p—calculated earlier

TE_i—data stored in the base data file.

MODEL DERIVATION

Category Code: 141-40, 141-70

Facility: Aircraft Operations Building With Control Tower

Definition of Facility:

An aircraft operations building and control tower is defined in the IFRS study to be one building including space for the administration of flight operational activities and a control tower providing space for equipment and personnel controlling air traffic. Since each training station is required to have a control tower and all towers are assumed to be the same size, the phase-to-base assignment will not affect the amount required of this facility. Thus the aircraft operations building and control tower are not included in the model.

MODEL DERIVATION

Category Code: 171-10

Facility: Academic Building
Facility No: 7

Definition of Facility:

The area required for academic instruction space is defined to include not only classroom space, but also space for administrative offices, assembly rooms, conference rooms, libraries, and lounges. Thus, the requirements for this facility include the gross area for all activities associated with academic instruction.

Calculation of Requirement:

The area required for classroom space by a student in a phase depends upon the number of class hours required for each student and phase length.

The requirement for classroom space by non-phase (tenant and NAS) personnel depends upon the number of tenant and NAS students.

Adjusted Tenant Requirements:

$$TCA_i = \left(\frac{(TS_i)(TH_i)}{CU_i}\right)(A)$$

where

TCA_i = total classroom area required by tenants at base i

CU_i = the number of annual hours that classroom space can be utilized for instruction

TS_i = annual number of students unrelated to a specific training phase requiring instruction at base i

TH_i = number of classroom hours per student of type TS

A = gross building area required per student.

Per Student Requirements:

$$SCA_p = \left(\frac{(52)(CH_p)}{(PL_p)(CU)}\right)(A)$$

where

SCA_p = total classroom area required by a student in phase p

52 = the number of weeks in the year

PL_p = phase length in weeks

CH_p = classroom hours required in phase p

A = gross building area required per student

CU = number of annual hours that a classroom space can be utilized for instruction.

Example:

Phase 7 Adv Jet TF

$CH_7 = 93$

$PL_7 = 20$

$CU = 2000$

$$SCA_7 = \left[\frac{(52)(93)}{(20)(2000)}\right] (75) = 8.72.$$

Tables A.3, A.4, and A.7 contain the coefficients for this facility.

Source of Independent Variables:

CHP—data stored in the LSR Generator data file

CU_i—stored in base data file

TS_i—stored in base data file

TH_i—stored in base data file

A—75 ft as specified in NAVFAC P-80

PH_p—stored in the LSR Generator data file.

MODEL DERIVATION

Category Code: 211-10

Facility: Maintenance Hangar
Facility No: 8

Definition of Facility:

The requirement for maintenance hangars is defined to include space for intermediate and organizational levels of maintenance for aircraft, aircraft spares, and components including hangar, shop, storage, and administrative space. The requirement does not include space for nose hangars, paint and finishing hangars, jet engine maintenance shop, or major rework facilities.

Calculation of Requirement:

Maintenance hangars are the basic aircraft maintenance facility at a naval air station. In general, maintenance is performed at two levels: the organizational level and the intermediate level. Each level of maintenance has a basic facility assigned to it with the size of the facility depending on the number and type of aircraft on the base. It is assumed that each facility is made up of modular units that may be constructed as separate buildings or incremented in various combinations to provide the necessary space. The two types of maintenance facilities consist of the following modules:

a. Organizational facility

1. Hangar module(s)

2. Crew and equipment/administrative module(s)

b. Intermediate facility

1. Shop module(s)

2. Crew and equipment/administrative module(s).

The number of modules required for an organizational facility is determined as follows:

a. Hangar Module: Requirement for hangar modules for each type of aircraft is determined by

$$\frac{AC_{pt}}{MAH_t}$$

where

AC_{pt} = aircraft of type t required by a student in phase p

MAH_t = maximum number of type t aircraft that can be supported by one hangar module.

b. Crew and Equipment/Administrative Module. Amount required for this category of the organizational facility is determined in a manner similar to the hangar module. The number of modules required is derived as

$$\frac{AC_{pt}}{MAC_t}$$

where

MAC_t = maximum number of type t aircraft that can be supported by one crew and equipment/administrative module.

The calculation of the requirement for the intermediate facility modules closely parallels that used for the organizational facilities, i.e.,

a. Shop Module. The total number of shop modules required is calculated in two stages. First, the number of basic shop modules required is calculated, which is simply the total number of aircraft on a base divided by the number of aircraft (144) that can be supported by one basic module. Thus, the number of basic modules required is:

$$\frac{AC_{pt}}{144}$$

Next, the number of supplementary shop modules required must also be calculated and added to the number of basic shop modules to give total shop modules. This calculation is carried out in the exact manner as the hangar module, i.e.,

$$\frac{AC_{pt}}{MAS_t}$$

MAS_t = maximum number of type t aircraft that can be supported by one shop module.

b. Crew and Equipment/Administrative Module. In addition to the shop modules, the intermediate level facility requires half a crew and equipment/administrative module. This half module is required regardless of the number of aircraft supported.

Thus, the total number of modules required by a base is the sum of the organizational facility modules and the intermediate facility modules.

The gross square feet allowed for each module are as follows:

- Hangar module—13,698
- Crew and equipment module—10,400
- Shop module—8,450.

Adjusted Tenant Requirements:

$$TMSF_i = \sum_{t=i}^{n} \frac{(13698)\ (TAC_{it})}{MAH_t} + \frac{(8450)\ (AC_{pt})}{MAC_t} +$$

$$\frac{(10400)\ (TAC_{it})}{144} + \frac{(10400)\ (TAC_{it})}{MAS_t} + 5200$$

where

$TMSF_i$ = tenant requirement for maintenance hangars at base i

TAC_{it} = the number tenant and NAS aircraft of type t at base i.

Per Student Requirements:

$$SMSF_p = \sum_{t=1}^{n} \frac{(13698)\ (AC_{pt})}{MAH_t} + \frac{(8450)\ (AC_{pt})}{MAC_t} +$$

$$\frac{(10400)\ (AC_{pt})}{144} + \frac{(10400)\ (AC_{pt})}{MAS_t}$$

Example:

Phase 7 Adv Jet TF

$AC/S = AC_p = .837$

MAH = 15

MAC = 24

MAS = 60.

Thus

$$SMSF_7 = \frac{(13698)\quad(.837)}{15} + \frac{(8450)\,(.837)}{24} +$$

$$\frac{(10400)\,(.837)}{144} + \frac{(10400)\,(.837)}{60}$$

$$SMSF_7 = 1265.$$

Tables A.3, A.4, and A.7 contain the coefficients for this facility.

<u>Source of Independent Variables:</u>

TAC_{it}—assigned to a base in the Base Loading submodel; tenant aircraft data are in the base data file.

MAH_t, MAC_t, MAS_t—data in the aircraft data file

AC_p—calculated earlier is equal to AC/S.

MODEL DERIVATION

Category Code: 219-10

Facility: Public Works Maintenance Shop

Facility No: 9

Definition of Facility:

The public works maintenance shop is defined to include space for the equipment and personnel required to maintain, repair, and overhaul installation facilities. Included within the definition is space for a woodworking shop, electric shop, plumbing and heating shop, metal work shop, paint shop, routine maintenance and service shop, and administrative office space.

Calculation of Requirement:

The calculation of the area required for a public works maintenance shop depends on the number of maintenance personnel on a base, which in turn is dependent on the total number of personnel (both military and civilian) at a base. Thus, the total number of maintenance personnel is derived by regression analysis and is given by the equation:

$$PWC_i = 75.78 + .0459 (SQ_i + TP_i)$$

where

PWC_i = number of public works personnel at base i

SQ_i = total number of squadron personnel at base i

TP_i = total number of tenant personnel at base i.

The gross square feet per public works employee was calculated by regression analysis to be:

$$TA_i = 4759 + 40 (PWC)$$

where

TA_i = total area required at base i.

Adjusted Tenant Requirements:

$$TPWA_i = 4759 + 40 (75 + .0459 (TP_i))$$

where

$TPWA_i$ = total tenant requirement for public works maintenance shops.

Per Student Requirements:

$$SPWA_p = (.0459)\ (40)\ (PP/S+1)$$

where

$SPWA_p$ = per student requirement for public works maintainance shops by students in phase p

PP/S = ratio of phase personnel (excluding students) to student load.

Example:

Phase 7 Adv Jet TF

$PP/S = 7.931$

$SPWA_7 = (.0459)\ (40)\ (7.931 + 1)$

$SPWA_7 = 16$

Tables A.3, A.4, and A.7 contain the coefficients for this facility.

Source of Independent Variables:

PP/S calculated earlier: TE_i—data in the base data file

MODEL DERIVATION

Category Codes: 442-10, 442-20, 442-30, 442-60, 442-65, 442-90

Facility: Covered Storage, Ready Issue

Facility No: 10

Definition of Facility:

Covered storage is defined in this study to cover two different types of structures: warehouse and shed. The facility definition includes space for all ready issue storage such as controlled humidity warehouse, hazardous and flammables storehouse, aviation warehouse, clothing and small stores, and miscellaneous storage. Excluded from the definition are bulk, perishable subsistence, transit, public works maintenance, and ground handling equipment storage.

Calculation of Requirement:

The total ready issue covered storage requirement for a naval air station is a function of both the number and type of aircraft at that station and the total number of base personnel. For purposes of requirement calculations, covered storage space is divided into warehouse space and shed space. Since NAS personnel require covered storage, the tenant and phase requirements must be factored up to reflect the NAS personnel required to support the squadrons and tenants. These personnel factors come from the regression equations in Phase II.

Adjusted Tenant Requirements:

$$TW_i = 1.018\left\{\left(\sum_{t=1}^{n}\left[(u_t)\ TAC_{it}\right)\right] + (10)(1.259\ TP_i + 518)\right\}$$

where

1.018 = the structure space factor for warehouses

TW_i = total square feet of warehouse space required by tenants at base i

u_t = warehouse space allowance per aircraft for type t aircraft

TAC_{it} = number of tenant type t aircraft at base i

10 = warehouse space allowance per person within base tenant population

TP_i = number of tenants at base i.

Similarly, the total amount of covered shed space required by the tenants can be expressed as:

$$TS_i = 1.015\left\{\sum_{t=1}^{n}\left[(\gamma_t)\ (TAC_{it})\right] + 1.5\ (1.259\ TP_i + 518)\right\}$$

where

TS_i = total square feet of shed space required by tenants at base i

γ_t = shed space allowance per aircraft for type t aircraft

TAC_{it} = number of type t tenant aircraft at base i

1.5 = shed space allowance per person within base tenant population

1.015 = structural space factor for covered shed.

Then total covered storage can be calculated as:

$$TCS_i = TW_i + TS_i$$

where

TCS_i = total covered storage required by tenants at base i.

Per Student Requirements:

$$SW_p = 1.018\left\{\sum_{t=1}^{n}\left[(u_t)\ (AC/S_{tp})\right] + (10)\ \ (1.259)(PP/S_p + 1)\right\}$$

where

SW_p = per student requirement for warehouses for phase p

AC/S_{tp} = number of aircraft of type t required by student in phase p

PP/S_p = ratio of phase personnel (excluding students to student load)

n = number of type t aircraft required for student in phase p

and

$$SS_p = 1.015\left\{\sum_{t=1}^{n}\left[(\gamma)\ \ (AC/S_{tp})\right] + (1.5)(1.259)(PP/S_p + 1)\right\}$$

where

SS_p = per student requirement for covered shed storage for phase p

and

$$SCS_p = SN_p + SS_p$$

where

SCS_p = per student requirement for covered storage for phase p.

Example:

Phase 7 Adv Jet TF

$u_t = 400$

$\gamma_t = 8$

$AC/S_7 = .837$

$PP/S_7 = 7.931$

$SW_7 = 1.018\Big((400)(.837) + 10\ (1.259)\ \ (7.931 + 1)\Big)$

$SW_7 = 454$

$SS_7 = 1.015\ (8)\ (.837) + 1.5\ (1.259)(7.931 + 1)$

$SS_7 = 24$

$SC_7 = 454 + 24$

$SCS_7 = 478.$

Tables A.3, A.4, and A.7 contain the coefficients for covered storage.

Source of Independent Variables:

u_t, γ_t—data in the aircraft data file

TAC_{it}—data in base data file

MODEL DERIVATION

Category Code: 550-10,550-20 Facility: Dispensary With Beds
Facility No: 11

Definition of Facility:

A dispensary is defined as a medical treatment facility that is primarily intended to provide examination and treatment of ambulatory patients, to make arrangements for transfer of patients to hospitals, and to render first aid in emergency cases. A dispensary may or may not include space for beds.

Calculation of Requirement:

The space required for a dispensary is assumed for planning purposes to be a function of total installation military strength, including military dependents, i.e., total number of eligible personnel. Since NAS personnel require dispensaries, the tenant and phase personnel are factored up to reflect the NAS personnel who support them. The basis for these personnel factors is the regression equations from Phase II. Assuming the average family size is 2.5,[1/] including the head of the household and using the P-80 planning factor of 3.7 square feet allowance per person the equations are as follows:

Adjusted Tenant Requirements:

$$TD_i = 3.7 \Big[2.5 \ (19.2 + (1.765\ TO_i)) \quad (C) + 19.2\ TO_i + 2.5\ (TE_i + 407 + .0939\ TP_i)\ ((A)(B) + E\ (1-A)) + TE_i + .0939\ TP + 407 \Big]$$

where

TD_i = tenant requirement for dispensaries at base i

TO_i = tenant officers at base i

TE_i = tenant enlisted men at base i

TP_i = tenant military population at base i

C = average fraction of all officers (excluding students in pilot training) requiring family housing

---

1/ Average U.S. family factor as noted in NAVFAC P-80.

A = fraction of enlisted men eligible for family housing

B = fraction of eligible enlisted men requiring family housing

E = fraction of ineligible enlisted men requiring family housing.

Per Student Requirements:

$$SD_p = 3.7\Big[2.5\,(1.1765(PO/S_p)(C) + D) + 1.1765(PO/S_p) + 1 + (2.5\,PE/S_p + 2.5\,(.0939\,PP/S_p))\Big((A)\,(B) + E\,(1-A)\Big) + PE/S_p + 1.0939\,PP/S\Big]$$

where

SD_p = per student requirement for dispensaries for phase p

PO/S_p = ratio of phase officers to student load in phase p

PE/S_p = ratio of phase enlisted to student load in phase p

PP/S_p = ratio of phase personnel (excluding students) to student load in phase p

D = fraction of students requiring family housing.

Example:

Phase 7 Adv Jet TF

A = .45

B = .78

C = .84

D = .47

E = .21

$PO/S_7 = 1.142$

$PE/S_7 = 6.788$

$PP/S_7 = 7.931$

Then

$$SD_7 = 3.7\Big[2.5\Big((1.1765)(1.142)(.84) + (.47)\Big) + \Big((1.1765)(1.142)\Big) + 1 + \Big((2.5)(6.788) + 2.5\quad(.0939)(7.931)\Big)\Big((.45)(.78) + .21\,(1-.45)\Big) + 6.788 + (1.0939)(7.931)\Big]$$

$$SD_7 = 145.1$$

Tables A.3, A.4, and A.7 contain the coefficients for this facility.

<u>Source of Independent Variables:</u>

A, B, C, D, E—data in the base data file.

MODEL DERIVATION

Category Code: 610-10

Facility: Administrative Office
Facility No: 12

Definition of Facility:

Administrative office space is defined as the area containing the offices of the commanding officer, the executive and administrative officers, and the space for military and civilian personnel required to carry the administrative workload of the activities of a base. It includes space for offices, business machines, records, files, administrative supplies, and other activities associated with general base activities. However, it does not include the administrative space located in maintenance hangars, warehouses or other buildings.

Calculation of Requirement:

The space allowance for the administrative offices is 162 square feet per occupant; thus, the total requirement for administrative office space can be expressed as

$$AO_i = 162\ (FA_i)\ (TBP_i)$$

where

AO_i = total square feet of central administrative office space required at base i

FA_i = fraction of total personnel at base i engaged in administration and occupying a central administrative facility

TBP_i = total number of personnel at base i including NAS, tenant, and squadron personnel.

Since NAS personnel are a function of the tenant and phase population, NAS requirements can be analyzed by factoring up the tenant and phase requirements. These factors were developed from regression analysis in Phase II.

Adjusted Tenant Requirements:

$$TAO_i = 162\ (FA)\left[(TP_i)\ (1.259) + 518\right]$$

where

TAO_i = tenant requirements for administrative office space.

Per Student Requirements:

$$SAO_p = 162\ (FA)\ (PP/S_p + 1)\ (1.259)$$

where

SAO_p = per student requirement for administration office space for phase p.

Example:

Phase 7 Adv Jet TF

$PP/S_7 = 7.931$

$FA = .1$

$SAO_7 = (162)(.1)(7.931 + 1)\ (1.259) = 182.$

Tables A.3, A.4, and A.7 contain the coefficients for this facility.

Source of Independent Variables:

FA_i—stored in the base data file.

MODEL DERIVATION

Category Code: 722-10

Facility: Enlisted Men's Barracks Without Mess

Facility No: 13

Definition of Facility:

Enlisted men's barrack requirements are defined to include public housing for bachelor enlisted personnel, both male and female, permanently stationed at a base. The available number of billets includes facilities with or without mess, but new facilities (if any) are assumed to be constructed without mess.

Calculation of Requirement:

Enlisted men's barracks are assumed to be provided for all enlisted men not requiring family housing. The total fraction of eligible enlisted men requiring family housing has previously been derived as

$$(A_i)(B_i)$$

while the total fraction of ineligible enlisted men requiring family housing is

$$(1-A_i)(E_i)$$

where

A = fraction of enlisted men eligible for family housing

B = fraction of eligible enlisted men requiring family housing

E = fraction of ineligible enlisted men requiring family housing.

NAS requirements are reflected by factoring up tenant and phase requirements.

Adjusted Tenant Requirements:

$$TBEM_i = \left\{1-\left[(A)(B) + (1-A)(E)\right]\right\}(TE_i + 407) + \left\{1-\left[(A)(B) + (1-A)(E)\right]\right\}(.0939\ TP_i)$$

where

$TBEM_i$ = enlisted barracks required by enlisted men at base i

TE_i = tenant enlisted at base i

TP_i = tenant population at base i.

Per Student Requirements:

$$SBEM_p = \left\{(1- [(A)(B) + (1-A)(E)]\right\}(PE/S_p) +$$

$$\left\{(1- [(A)(B) + (1-A)(E)]\right\}(.0939\ PP/S_p)$$

where

$SBEM_p$ = per student requirement for enlisted barracks in phase p

PE/S_p = ratio of phase enlisted men to student load in phase p

PP/S_p = ratio of phase population (excluding students) to student load in phase p.

Example:

Phase 7 Adv Jet TF

$PE/S_7 = 6.788$

$PP/S_7 = 7.931$

$A = .45$

$B = .78$

$E = .21$

$$SBEM_7 = \left\{1- [(.45)(.78) + (1-.45)(.21)]\right\}(6.788) +$$

$$\left\{1- [(.45)(.78) + (1-.45)(.21)]\right\}(.0939)(7.931)$$

$$SBEM_7 = 4.366.$$

Tables A.3, A.4, and A.7 contain the coefficients for this facility.

Source of Independent Variables:

A_i, B_i, E_i—data in the base data file.

MODEL DERIVATION

Category Code: 723-10

Facility: Mess Hall
Facility No: 14

Definition of Facility:

Mess hall space allowances are defined to include the total area required for a cafeteria-type dining facility including food storage space, kitchen space, serving space, and dining space. Excluded is space required for heating, mechanical, and electrical heating equipment.

Calculation of Requirement:

Mess hall requirements are calculated from the requirement for enlisted men's barracks.

Adjusted Tenant Requirements:

$$TMHC_i = (MH_i)(TBEM_i)$$

where

$TMHC_i$ = tenant enlisted men's mess hall capacity required at base i

$TBEM_i$ = tenant enlisted men's barrack capacity at base i

MH_i = fraction of total enlisted mess barrack capacity utilizing mess facilities.

The total floor area required for dining facilities for tenants is

$$TMHA_i = (FA)(TMHC_i)$$

where

$TMHA_i$ = gross square feet of floor area required for tenant dining facilities at base i

FA = floor area allowance in square feet per person (15 ft).

Per Student Requirements:

$$SMHC_p = (MH_p)(SBEM_p)$$

where

$SMHC_p$ = per student mess hall capacity required for phase p

$SBEM_p$ = per student requirement for enlisted men's barracks in phase p

MH_p = fraction of phase enlisted mess barrack capacity utilizing mess facilities

and

$$SMHA_p = (FA)(SMHC_p)$$

where

$SMHA_p$ = per student gross square feet of floor area required by phase p.

Example:

Phase 7 Adv Jet TF

$SBEM_7 = 4.3661$

$MH_7 = .85$

$SMHC_7 = (.85)(4.3661)$

$SMHA_7 = (.85)(4.3661)(15)$

$SMHA_7 = 55.67.$

Tables A.3, A.4, and A.7 contain the coefficients for this facility.

Source of Independent Variables:

$SBEM_p$, $TBEM_i$—calculated for Category Code 722-10

MH_i—data in the base data file.

MODEL DERIVATION

<u>Category Code:</u> 724-15

<u>Facility:</u> BOQs Without Mess
<u>Facility No:</u> 15

<u>Definition of Facility:</u>

Bachelor officers' quarters are defined to include billets for the installation's bachelor officer strength, including male and female officers, officer students, transients, and/or rotational officer personnel. Phase, tenant, and NAS officers are included within total requirements.

<u>Calculation of Requirement:</u>

The calculation of the requirement for BOQs assumes that all new BOQs will be planned without mess facilities. The calculation further assumes that all officers (and students) not utilizing family housing require billets on base. NAS requirements for BOQs are reflected by factoring up the tenant and phase requirements by factors developed through regression analysis in Phase II.

<u>Adjusted Tenant Requirements:</u>

$$TBOQ_i = (1-C)\left[1.1765\,(TO_i + 19)\right]$$

where

$TBOQ_i$ = total number of BOQ billets required by tenants at base i

C = fraction of officers (excluding students in pilot training programs) requiring family housing

TO_i = number of tenant officers at base i.

<u>Per Student Requirements:</u>

$$SBOQ_p = (1-D) + (1-C)\left[1.1765\,(PO/S_p)\right]$$

where

$SBOQ_p$ = per student requirement for BOQs of phase p

D = fraction of students in pilot training programs requiring family housing

PO/S_p = ratio of phase officers to student load in phase p.

Example:

Phase 7 Adv Jet TF

$PO/S_p = 1.142$

$C = .84$

$D = .47$

$$SBOQ_7 = (1-.47) + (1-.84)(1.1765)(1.142)$$

$$SBOQ_7 = .7750.$$

Tables A.3, A.4, and A.7 contain the coefficients for this facility.

Source of Independent Variables:

C_i, D_i—data in the base data file.

MODEL DERIVATION

Category Code: 740-14

Facility: Exchange
Facility No: 16

Definition of Facility:

The components of the "standard" IFRS exchange are listed below. Space allowance factors for the exchange include space for sales area, stock area, officers, toilets, and entrance facilities, but excludes warehouse space.

Calculation of Requirement:

For this study, a standard exchange has been defined to include the following facilities:

- Main retail store
- Exchange cafeteria
- Exchange maintenance shop
- Barber shop
- Exchange central administrative facility.

Each of these facilities has a floor area associated with it; its size depends on the military strength of the base. The sum of all these facility floor areas is assumed to be the total floor area requirement for an exchange. NAS requirements are reflected by factoring up tenant and phase requirements with factors developed through regression analysis in Phase II.

Adjusted Tenant Requirements:

$$TER_i = FAR\left[(19.2 + 1.177\ TO_i) + (1.094\ TE_i + 408)\right]$$

where

TER_i = tenant exchange requirements at base i

FAR = floor area requirement per user (3.5)

TO_i = tenant officers at base i

TE_i = tenant enlisted men at base i .

Per Student Requirements:

$$SER_p = FAR\left[1.177\ (PO/S_p + 1) + 1.0939\ (PE/S_p)\right]$$

where

SER_p = per student exchange requirement for phase p

PO/S_p = ratio of phase officers to student load in phase p

PE/S_p = ratio of phase enlisted to student load in phase p

Example:

Phase 7 Adv Jet TF

$PO/S_7 = 1.142$

$PE/S_7 = 6.788$

$FAR = 3.5$

$$SER_7 = 3.5 \left[1.177\ (1.142 + 1) + (1.0939)(6.788)\right]$$

$SER_7 = 38.$

Tables A.3, A.4, and A.7 contain the coefficients for this facility.

MODEL DERIVATION

Category Code: 740-63

Facility: Enlisted Men's Service Club

Facility No: 17

Definition of Facility:

An enlisted men's service club space allowance is defined to include all facilities within the club including the bar, eating facilities, toilets, etc.

Calculation of Requirement:

The size of an enlisted men's service club depends on the total number of enlisted men stationed at a base. NAS requirements are reflected by factoring up tenant and phase requirements.

Adjusted Tenant Requirements:

$$TEMS_i = 5.25(407 + 1.0939\ TE) + 3597$$

where

$TEMS_i$ = tenant requirement for service clubs at base i

TE_i = tenant enlisted at base i.

Per Student Requirements:

$$SEMS_p = (PE/S_p)(1.0939)(5.25)$$

where

$SEMS_p$ = per student requirement for service clubs for phase p

PE/S_p = ratio of phase enlisted men to student load in phase p.

Example:

Phase 7 Adv Jet TF

$PE/S_7 = 6.788$

$$SEMS_7 = (6.788)(1.0939)(5.25)$$

$$SEMS_7 = 39.$$

Tables A.3, A.4, and A.7 contain the coefficients for this facility.

MODEL DERIVATION

Category Code: 812-30

Facility: Distribution Line (Electrical)

Facility No: 18

Definition of Facility:

Distribution lines are defined to include all lines connecting power sources to consuming facilities. The power sources may be off base or a reserve generator equipment on base. Both overhead and underground distribution lines are included in the definition. Distribution lines within 5 feet of a source or consuming facility are not included, as they are defined as a part of the facility.

Calculation of Requirement:

The length of electrical distribution line required at a base is estimated by regression analysis.

Adjusted Tenant Requirements:

$$TEDL_i = 54.9\ (TP_i)$$

where

$TEDL_i$ = total feet of electrical distribution line required by tenants at base i

TP_i = total number of tenant personnel at base i.

Per Student Requirements:

$$SEDL_p = (PP/S_p + 1)\ 54.9$$

where

$SEDL_p$ = per student requirement for electrical distribution lines for phase p

PP/S_p = the ratio of phase personnel (excluding students to student load for phase p.

Example:

Phase 7 Adv Jet TF

$PP/S_p = 7.931$

$$SEDL_p = (7.931 + 1)\ 54.9$$

$$SEDL_p = 490.$$

Tables A.3, A.4, and A.7 contain the coefficients for this facility.

MODEL DERIVATION

Category Code: 842-10

Facility: Water Distribution Line (Potable)

Facility No: 19

Definition of Facility:

Water distribution lines are defined to include all lines from a storage tank or a treatment plant to station demand points. The storage tank or treatment plant may be on or off base. Distribution lines within 5 feet of a facility are not included, as they are defined to be a part of that facility.

Calculation of Requirement:

The length of a water distribution line required by a base is estimated by regression analysis to be

$$WDL_i = -76400 + 40.5\ (SQ_i + TE_i) + 105\ (SL_i)$$

where

WDL_i = total feet of water distribution line required at base i

SQ_i = total number of squadron personnel at base i

TE_i = total number of tenant personnel at base i

SL_i = average student load at base i.

From this equation, the tenant and phase requirements can be calculated.

Adjusted Tenant Requirements:

$$TWDL_i = 40.5(TP_i) - 76400$$

where

$TWDL_i$ = tenant requirement for water distribution lines at base i

TP_i = tenant population at base i.

Per Student Requirements:

$$SWDL_p = 40.5\ (PP/S_p + 1) + 105$$

where

$SWDL_p$ = per student requirement for water distribution lines for phase p

PP/S_p = ratio of phase personnel (excluding students) to student load for phase p.

<u>Example:</u>

Phase 7 Adv Jet TF

$PP/S_p = 7.931$

$$SWDL_7 = 40.5(7.931 + 1) + 105$$

$$SWDL_7 = 467.$$

Tables A.3, A.4, and A.7 contain the coefficients for this facility.

MODEL DERIVATION

Category Code: 851-10, 851-11, 851-12 Facility: Roads
Facility No: 20

Definition of Facility:

The road requirement is defined to encompass roads of all types including primary (major traffic arteries), secondary (access roads with a moderate traffic volume), and tertiary roads (providing access to individual buildings or groups of buildings). The requirement includes roads on the grounds of activities and noncontiguous areas.

Calculation of Requirement:

The total miles of roads required at a base are estimated by regression analysis to be

$$MR_i = -11.5 + .0224\ (EMS_i + TE_i)$$

where

MR_i = total miles of roads required at base i

EMS_i = total squadron enlisted men at base i

TE_i = total enlisted tenants at base i.

From this equation, tenant and phase requirements can be developed.

Adjusted Tenant Requirements:

$$TMR_i = .0224\ TE_i - 11.5$$

where

TMR_i = tenant requirement for roads.

Per Student Requirements:

$$SMR_p = .0224\ PE/S_p$$

where

SMR_p = per student requirement roads for phase p

PE/S_p = ratio of phase enlisted to student load in phase p.

Example:

Phase 7 Adv Jet TF

$PE/S_7 = 6.788$

$SMR_7 = (.0224)(6.788)$

$SMR_7 = .152.$

Tables A.3, A.4, and A.7 contain the coefficients for this facility.

MODEL DERIVATION

Category Code: 852-10, 852-11, 852-12 (852-80)

Facility: Auto Parking Areas
Facility No: 21

Definition of Facility:

The requirement for parking areas is defined to include all parking areas at a base for off-street parking of passenger cars and trucks, both organizational and nonorganizational, including parking areas located on the ground of activities and noncontiguous areas. Area allowances include space for parking and for paved access and exit areas.

Calculation of Requirement:

The total parking area required at a base is estimated by regression analysis to be

$$PA_i = -80000 + 128\ (EMS_i + TE_i)$$

where

PA_i = total parking area in square yards required at base i

EMS_i = total squadron enlisted men at base i

TE_i = total enlisted tenants at base i.

From this equation, tenant and phase requirements can be developed.

Adjusted Tenant Requirements:

$$TPA_i = 128\ TE_i - 80000$$

where

TPA_i = tenant requirement for parking area at base i.

Per Student Requirements:

$$SPA_p = 128\ PE/S_p$$

where

SPA_p = per student requirement for parking area in phase p

PE/S_p = ratio of phase enlisted to student load in phase p.

Example:

Phase 7 Adv Jet TF

$PE/S_7 = 6.788$

$SPA_7 = (6.788)(128)$

$SPA_7 = 869.$

Tables A.3, A.4, and A.7 contain the coefficients for this facility.

MODEL DERIVATION

Category Code: 711-10 through 62

Facility: Family Housing (Officers and Eligible Enlisted)

Facility No: 22

Definition of Facility:

Family housing in this category is defined to be required for all eligible military personnel (including students) with dependents. No distinctions are made between housing types or housing unit sizes. Housing requirements are defined to be fulfilled by either military-owned or military-occupied housing. Thus, facility requirements can be fulfilled by privately-owned housing units or military units. Housing requirements for NAS personnel are reflected by factoring up tenant and phase requirements through factors developed with regression analysis in Phase II.

Adjusted Tenant Requirements:

$$TFH_i = (19.23 + 1.1765\ TO_i)(C) + (A)(B)(407 + TE_i) + (A)(B)(.0939\ TP_i)$$

where

TFH_i = tenant requirement for family housing at base i

TO_i = tenant officers at base i

TE_i = tenant enlisted at base i

TP_i = tenant population at base i

A = fraction of enlisted men eligible for family housing

B = fraction of eligible enlisted men requiring family housing

C = average fraction of all officers (excluding students in pilot training) requiring family housing.

Per Student Requirements:

$$SFH_p = (1.1765\ PO/S_p)(C) + D + (A)(B)(PE/S_p) + (A)(B)(.0939)(PP/S_p)$$

where

SFH_p = per student family housing requirement for phase p

PO/S_p = the ratio of phase officers to student load in phase p

PE/S_p = the ratio of phase enlisted to student load in phase p

PP/S_p = the ratio of phase personnel (excluding students) to student load in phase p

D = fraction of pilot students requiring family housing.

<u>Example:</u>

Phase 7 Adv Jet TF

A = .45	$PO/S_7 = 1.142$
B = .78	$PE/S_7 = 6.788$
C = .84	$PP/S_7 = 7.931$
D = .47	

$$SFH_7 = (1.1765)(1.142)(.84) + .47 + (.45)(.78)(6.788) + (.45)(.78)(.0939)(7.931)$$

$$SFH_7 = 4.2.$$

Tables A.3, A.4, and A.7 contain the coefficients for this facility.

<u>Source of Independent Variables:</u>

A_i, B_i, C_i, D_i—data in the base data file as obtained from DD Form 1378.

TABLE A.3

PER STUDENT FACILITY REQUIREMENT BY FACILITY LINE ITEM AND PHASE

Phase Number	Facility Number																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
	RY_1/S_p	RY_2/S_p	RY_3/S_p	SPA_p	$SBFS_p$	SDP_p	SCA_p	$SMSF_p$	$SPWA_p$	SCS_p	SD_p	SAD_p	$SBEM_p$	$SMHA_p$	$SBOO_p$	SER_p	$SEMS_p$	$SEDL_p$	$SWDL_p$	SMR_p	SPA_p	SFH_p
1	0	0	0	0	0	.0014	91.68	0	2	15	8.5	21	.0028	.0357	.5656	4	0	57	147	0	0	.5
2	0	0	0	0	0	.0014	75.	0	2	15	8.5	21	.0030	.03825	.5660	4	0	57	147	0	0	.5
3	.002829	0	0	*	102	.0035	15.62	305	5	96	33.8	52	.6823	8.69933	.6590	10	6	139	208	.023	129	1.4
4	0	.003341	0	*	2,487	.0055	11.12	351	7	206	59.4	82	1.4829	18.907	.6803	16	14	220	267	.053	302	2.0
5	0	.004088	0	*	4,400	.0094	16.69	558	13	331	109.1	140	3.2169	41.0155	.7202	27	29	376	382	.112	640	3.3
6	0	.004447	0	*	2,824	.0081	0	269	11	274	92.4	120	2.7216	34.7	.6780	23	24	322	343	.095	543	2.7
7	0	0	.008155	*	8,829	.0123	8.72	1,265	16	478	145.1	182	4.3661	55.6678	.7750	38	39	490	467	.152	869	4.2
8	0	0	.008159	*	6,865	.0113	8.72	1,115	15	428	132.2	167	3.9286	50.09	.7657	32	35	450	437	.137	781	3.9
9	0	.002075	0	*	473	.0053	16.20	406	7	136	62.7	78	1.4666	18.71	.6639	15	13	210	260	.051	290	2.0
10	0	.003489	0	*	286	.0047	0	274	6	105	49.6	70	1.3037	16.622	.6342	14	12	187	243	.045	258	1.6
11	0	0	.004389	*	1,065	.0039	48.84	689	12	269	103.1	133	3.0028	38.286	.7119	25	27	357	368	.105	601	3.1
12	0	.0006535	0	*	483	.0053	0	408	7	137	57.1	79	1.4966	19.082	.6654	15	13	212	262	.052	294	1.9
13	0	.002518	0	*	360	.0044	13.88	250	6	96	45	65	1.1072	14.117	.6485	12	10	174	233	.038	216	1.6
14	.009955	0	0	*	116	.0044	16.41	658	6	127	45.6	66	1.0514	13.405	.6805	13	9	177	235	.035	202	1.7
15	.005605	0	0	*	1,081	.0082	8.19	853	11	192	92.8	121	2.6289	33.5185	.7238	24	23	326	345	.091	520	2.9
Facility Unit Cost	1,438,364	4,117,970	6,700,558	11.24	1.057	66,767	29.11	30.94	28.24	13.24	47.63	27.94	3,692	51.57	13,571	34.07	35.99	6.06	11.54	71,595	4.30	22,656

*See Table A.5.

TABLE A.4

PER STUDENT COST OF BUILDING NEW FACILITIES BY PHASE

Phase Number	Facility Number 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	0	0	0	0	0	93	2,669	0	56	199	405	587	10	2	7,676	136	0	345	1,696	0	0	11,328
2	0	0	0	0	0	93	2,183	0	56	199	405	587	11	2	7,681	136	0	345	1,696	0	0	11,328
3	4,069	0	0	*	107	234	455	9,436	141	1,271	610	1,453	2,519	450	8,944	341	216	842	2,400	1,647	555	31,719
4	0	13,758	0	*	2,621	367	324	10,859	198	2,728	2,853	2,291	5,475	975	9,233	545	504	1,333	3,081	3,795	1,229	45,312
5	0	16,834	0	*	4,637	628	486	17,263	367	4,449	5,197	3,911	11,877	2,115	9,774	920	1,044	2,278	4,408	8,019	2,752	74,765
6	0	18,313	0	*	2,976	541	0	8,322	311	3,628	4,401	3,352	10,048	1,790	9,201	784	864	1,951	3,958	6,802	2,335	61,172
7	0	0	54,643	*	9,304	821	254	39,135	452	6,329	6,911	5,084	16,120	2,871	10,518	1,295	1,403	2,969	5,389	10,882	3,737	95,156
8	0	0	54,670	*	7,234	754	254	34,495	424	5,667	6,292	4,665	14,505	2,583	10,392	1,090	1,260	2,727	5,042	9,809	3,358	88,359
9	0	8,545	0	*	498	354	486	12,560	198	1,801	2,986	2,179	5,415	964	9,010	511	468	1,272	3,000	3,651	1,247	45,312
10	0	14,368	0	*	301	314	0	8,477	169	1,390	2,363	1,956	4,813	857	8,607	477	432	1,133	2,804	3,222	1,109	36,250
11	0	0	29,409	*	1,122	594	1,422	21,316	339	3,562	4,911	3,715	1,187	1,974	9,662	852	972	2,163	4,246	7,517	2,584	70,234
12	0	2,692	0	*	509	354	0	12,622	198	1,814	2,720	2,207	5,526	981	9,030	511	468	1,285	3,023	3,723	1,264	43,047
13	0	10,369	0	*	379	294	404	7,734	169	1,271	2,143	1,816	4,088	728	8,801	409	360	1,054	2,689	2,721	929	36,250
14	14,319	0	0	*	122	294	478	20,357	169	1,682	2,172	1,844	3,882	691	9,235	443	324	1,072	2,712	2,506	869	38,515
15	8,062	0	0	*	1,139	547	238	26,389	311	2,542	4,420	3,380	9,706	1,729	9,823	818	828	1,993	3,931	6,515	2,236	65,703

*See Table A.6.

TABLE A.5

PER STUDENT REQUIREMENT FOR AIRCRAFT PARKING APRON BY PHASE AND BASE

Base	Phase Number 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Chas	0	0	436.2	914.1	1463.6	1171.9	2009.4	1325.6	818.0	550.9	500.8	821.7	504.2	1460.7	2752.8
2. Corp	0	0	273.3	568.4	910.0	728.6	1253.0	834.9	501.0	337.4	311.8	503.3	308.8	903.5	1668.9
3. Elly	0	0	221.4	459.2	735.2	588.7	1013.3	677.3	402.9	271.3	252.0	404.7	248.3	728.7	1337.8
4. King	0	0	386.8	808.7	1294.8	1036.7	1779.2	1177.3	720.3	485.1	443.2	723.6	444.0	1290.2	2416.5
5. Meri	0	0	258.2	536.5	859.0	687.8	1183.0	789.0	472.3	318.1	294.4	474.4	291.1	852.4	1571.7
6. Pens	0	0	320.3	667.6	1068.9	855.8	1470.5	976.9	591.0	398.0	366.1	593.7	364.3	1062.8	1974.3
7. Sauf	0	0	303.4	631.8	1011.6	809.9	1392.0	925.8	558.4	376.1	346.5	561.0	344.2	1005.2	1863.6
8. Whit	0	0	309.7	645.1	1032.8	826.9	1421.1	944.8	570.5	384.2	353.8	573.1	351.7	1026.6	1904.6

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DEVELOPMENT OF THE OPTIMIZATION MODEL FOR THE INTEGRATED FACILI--ETC(U)
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TABLE A.6

COST PER STUDENT FOR AIRCRAFT PARKING APRON

Phase	Base							
	1	2	3	4	5	6	7	8
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	4,901	3,069	2,484	4,339	2,900	3,597	3,406	3,473
4	10,273	6,384	5,159	9,082	6,025	7,497	7,092	7,250
5	16,444	10,228	8,261	14,545	9,655	12,004	11,364	11,600
6	13,162	8,183	6,607	11,645	7,722	9,610	9,093	9,284
7	22,581	14,084	11,386	19,996	13,297	16,523	15,646	15,972
8	14,893	9,385	7,609	13,229	8,868	10,970	10,397	10,611
9	9,194	5,631	4,518	8,093	5,305	6,643	6,272	6,407
10	6,182	3,788	3,046	5,451	3,574	4,474	4,226	4,316
11	5,620	3,496	2,832	4,979	3,505	4,114	3,889	3,968
12	9,228	5,654	4,541	8,127	5,328	6,665	6,306	6,441
13	5,665	3,462	2,788	4,991	3,271	4,091	3,867	3,945
14	16,410	10,150	8,183	12,500	9,576	11,937	11,296	11,532
15	30,932	18,748	15,028	27,156	17,658	22,188	20,940	21,401

TABLE A.7

ADJUSTED TENANT DEMAND FOR EACH FACILITY LINE ITEM

Base	Facility Number* 1 RY_{1_i}	2 RY_{2_i}	3 RY_{3_i}	4 TPA_i	5 $TBSF_i$	6 TDP_i	7 TCA_i	8 $TMSF_i$	9 $TPWA_i$	10 TCS_i	11 TD_i
1. Chas	0	0	0	38,714	7,722	0	0	12,571	7,759	[illegible],346	3,482
2. Corp	0	0	0	51,021	22,772	7.9	0	18,537	18,349	91,719	15,900
3. Eily	0	0	0	59.638	33,557	0	0	22,191	7,759	9,447	3,482
4. King	0	0	0	26,544	13,555	0	0	11,194	7,759	7,355	3,482
5. Meri	0	0	0	34,258	13,555	.07	0	11,194	7,854	8,105	3,833
6. Pens	0	0	0	131,305	128,035	13.3	0	63,772	22,000	157,765	23,479
7. Sauf	0	0	0	33,740	18,726	0	0	10,548	7,759	7,201	3,482
8. Whit	0	0	0	30,117	8,447	.08	0	8,693	7,846	7,098	3,768

Base	12 TAD_i	13 $TBEM_i$	14 $TMHA_i$	15 $TBOQ_i$	16 TER_i	17 $TEMS_i$	18 $TEDL_i$	19 $TWDL_i$	20 TMR_i	21 TPA_i	22 TFH_i
1. Chas	8,392	217	2,767	4	1,495	5,734	0	-76,400	-11.5	-80,000	157
2. Corp	126,035	875	11,156	41	4,957	9,708	316,663	157,204	5.	8,576	787
3. Eily	8,392	217	2,767	4	1,495	5,734	0	-76,400	-11.5	-80,000	157
4. King	8,392	217	2,767	4	1,495	5,734	0	-76,400	-11.5	-80,000	159
5. Meri	9,453	230	2,933	6	1,618	5,837	2,856	-74,294	-11.1	-77,886	180
6. Pens	205,497	1,126	14,367	97	6,578	10,305	530,584	314,882	6.3	21,888	1,245
7. Sauf	8,392	217	2,767	4	1,486	5,734	0	-76,400	-11.5	-80,000	159
8. Whit	9,351	234	2,984	4	1,610	5,886	2,880	-74,486	-10.9	-76,416	172

* See Table A.9 for facility name.

TABLE A.8

PER STUDENT COST OF BUILDING ALL FACILITY LINE ITEMS
BY PHASE AND BASE

Phase No.	Base Name and Number							
	Chas	Corp	Elly	King	Meri	Pens	Sauf	Whit
1	25,192	25,192	25,192	25,192	25,192	25,192	25,192	25,192
2	24,722	24,722	24,722	24,722	24,722	24,722	24,722	24,722
3	72,308	70,478	69,894	71,754	70,308	71,006	70,816	70,867
4	117,755	113,869	112,642	116,570	113,511	114,984	114,581	114,731
5	188,173	181,952	179,987	186,276	181,378	183,736	183,092	183,331
6	153,919	148,938	147,365	152,400	148,478	150,367	149,851	150,043
7	295,840	287,360	284,665	293,274	286,573	289,804	288,922	289,249
8	268,808	263,293	261,522	267,141	262,777	264,889	264,315	264,528
9	109,650	106,088	104,985	108,553	105,765	107,099	106,733	106,869
10	95,729	92,830	92,087	94,490	92,612	93,511	93,264	93,356
11	173,409	171,286	170,614	172,762	171,089	171,896	171,675	171,757
12	101,209	97,631	96,523	100,107	97,306	98,646	98,279	98,415
13	88,274	86,079	85,399	87,599	85,880	86,702	86,477	86,561
14	118,102	111,840	109,876	116,186	111,266	113,630	112,983	113,223
15	181,297	169,116	165,395	177,517	168,023	172,548	176,304	171,765
Minimizer Objective Function Terms	1-15	16-30	31-45	46-60	61-75	76-90	91-105	106-120

TABLE A.9

FACILITY LINE ITEMS

Number	Name
1	3,000 ft runway system (runway, taxiway, lighting)
2	5,000 ft runway system (runway, taxiway, lighting)
3	8,000 ft runway system (runway, taxiway, lighting)
4	Aircraft parking apron
5	Aircraft ready fuel storage
6	Underground distribution pipeline
7	Academic building
8	Aircraft maintenance hangars
9	Public works maintenance shops
10	General warehouses (covered storage)
11	Dispensary with beds
12	Administrative offices
13	Enlisted men's barracks with/without mess
14	Mess hall
15	BOQs without mess
16	Exchange
17	Enlisted men's service club
18	Electrical distribution lines
19	Water distribution lines
20	Roads
21	Auto parking aprons
22	Family housing